# A STUDY OF PREDICTED ENERGY SAVINGS AND SENSITIVITY ANALYSIS

A Thesis

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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August 2013

Major Subject: Architecture

## ABSTRACT

The sensitivity of the important inputs and the savings prediction function reliability for the WinAM 4.3 software is studied in this research. WinAM was developed by the Continuous Commissioning® (CC®) group in the Energy Systems Laboratory at Texas A&M University. For the sensitivity analysis task, fourteen inputs are studied by adjusting one input at a time within ± 30% compared with its baseline. The Single Duct Variable Air Volume (SDVAV) system with and without the economizer has been applied to the square zone model. Mean Bias Error (MBE) and Influence Coefficient (IC) have been selected as the statistical methods to analyze the outputs that are obtained from WinAM 4.3. For the saving prediction reliability analysis task, eleven Continuous Commissioning® projects have been selected. After reviewing each project, seven of the eleven have been chosen. The measured energy consumption data for the seven projects is compared with the simulated energy consumption data that has been obtained from WinAM 4.3. Normalization Mean Bias Error (NMBE) and Coefficient of Variation of the Root Mean Squared Error (CV (RMSE)) statistical methods have been used to analyze the results from real measured data and simulated data.

Highly sensitive parameters for each energy resource of the system with the economizer and the system without the economizer have been generated in the sensitivity analysis task. The main result of the savings prediction reliability analysis is that calibration improves the model's quality. It also improves the predicted energy savings results compared with the results generated from the uncalibrated model.

## ACKNOWLEDGEMENTS

I would like to express my very great appreciation to Professor Charles H. Culp, for his valuable suggestions, patience and understanding during the planning and development of this research work. I would like to express my deep gratitude to Professor Wei Yan and Professor Sarel Lavy for their consideration and patience to me during this research.

One of the Chinese old saying's "He who teaches me for one day is my father for life." I really appreciate them that they are my Professors.

I would like to offer my special thanks to Kevin Christman, Dr. Charles Lindsey, and Mrs. Bonita Culp. The advice given by them has been a great help in this research.

I would like to thank the Energy Systems Laboratory for financially supporting me as I finished this research.

I would also like to extend my thanks to the co-workers in the ESL and the staff on campus.

Finally, I want to thank my parents for their support and encouragement throughout my study.

## NOMENCLATURE

| | |
|---|---|
| APE | Absolute Percentage Error |
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| CC® | Continuous Commissioning® |
| CV (RMSE) | Coefficient of Variation of the Root Mean Squared Error |
| DSA | Differential Sensitivity Analysis |
| EP | Error Percentage |
| FP | VAV fan power |
| IC | Influence Coefficient |
| IP | Interior zone percentage |
| Max | Maximum airflow |
| MCA | Monte Carlo Analysis |
| Min | Minimum airflow |
| NLPL | Nighttime lighting and plug load ratio |
| NMBE | Normalized Mean Bias Error |
| OA | Outside air percentage |
| OAT | Outside air temperature |
| Occ | Peak occupancy |
| Roof U | Roof U-value |
| SA | Sensitivity Analysis |
| SDVAV | Single Duct Variable Air Volume |

| | |
|---|---|
| SHGC | Solar Heat Gain Coefficient |
| SSA | Stochastic sensitivity analysis |
| Tc | Cooling coil temperature |
| Tz | Zone temperature |
| UA | Uncertainty Analysis |
| Wall U | Exterior wall U-value |
| Window U | Exterior window U-value |
| W-W | Window-wall ratio |

# TABLE OF CONTENTS

Page

## LIST OF FIGURES

Page

Page

Page

Page

Page

Page

## LIST OF TABLES

Page

Page

# 1. INTRODUCTION

The purpose of this research is to analyze the performance of WinAM 4.3. WinAM 4.3 is building performance and energy savings prediction software. It was created by the Continuous Commissioning® (CC®) group in the Energy Systems Laboratory at Texas A&M University. The use of WinAM 4.3 helps CC® licensees estimate the savings for applying CC® measures. WinAM 4.3 can also identify potential energy or cost retrofits and estimate the performance of retrofits (ESL 2012). The approach used in this study will be to perform Sensitivity Analysis (SA) to determine the impact of the major parameters used in WinAM 4.3. In addition, the reliability of the savings estimated will be determined by comparing the calculated savings with the savings reported.

The results of the sensitivity analysis task shows the variation in energy consumption that each input parameter has as it is varied over a range of approximately ±30% from the normal value. 14 parameters from WinAM 4.3 software have been chosen for this task, 162 models have be generated after adjusting each parameter within $\pm$ 30% based on base case model. For example, the outside air input variable showed a higher variability than the same percentage of change of Roof U-value for chilled water consumption in a single duct variable air volume system (SD-VAV).

In the savings potential reliability analysis, seven CC® projects were selected as representative samples to be examined. These include office buildings, a hospital, a kindergarten, and two airport buildings. Calibration results for one of the office buildings, Austin City Hall, were also produced using both the WinAM 4.3 and the eQUEST 3-64 (Hirsch et al. 2010) simulation software to see the impact of different simulation engines on the savings results. eQUEST is one of the most popular software packages for analyzing building energy performance (Crawley 2004). This analysis provides a comparison and reference point for the WinAM 4.3 results.

Highly sensitive parameters for each energy resource of the systems with and without the economizer are generated in the sensitivity analysis task. The main result of the savings prediction reliability analysis is that calibration improves the model's quality. It also improves the predicted energy savings results compared with the results generated from the uncalibrated models.

# 2. LITERATURE REVIEW

## 2.1 Statistical methods for simulated model calibration

ASHRAE Guideline 14-2002 (ASHRAE 2002). The ASHRAE acceptance criteria for calibrated models require the normalized mean bias error (NMBE (%)) to be within ±10% and the coefficient of variation of the root mean square error (CV(RMSE)(%)) to be within ±30% when using hourly data or ±5% and ± 15% when using monthly data, respectively.

$$\text{CV(RMSE) (\%)} = \left(\sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y}_i)^2}{n-p}}\right).\left(\frac{100}{\bar{y}}\right) \qquad \text{Equation 2.1}$$

$$\text{NMBE (\%)} = \left(\frac{\sum_{i=1}^{n}(y_i-\hat{y}_i)}{n-p}\right).\left(\frac{100}{\bar{y}}\right) \qquad \text{Equation 2.2}$$

$y_i$= Utility data used for calibration

i= Simulation-predicted data

$\hat{y}_i$= The mean value of the utility data

i= Instance

p= 1

## 2.2 Sensitivity Analysis (SA) and Uncertainty Analysis (UA)

### 2.2.1 Sensitivity Analysis (SA)

In his literature review, Tian (2013) summarized prior work in three areas where sensitivity analysis is important.

1. By understanding the sensitivity of the inputs, people can understand the impact of saving measures from them and get potential saving (Petr et al. 2007; Lam 2008).
2. Uncertainty and sensitivity analysis coupled with building performance software has the potential to be used for accuracy assessment, design robustness assessment and design guidance (Struck 2009).
3. By detecting the most sensitive input parameter, sensitivity and uncertainty analysis can help the user determine which area of the building needs to be improved (Purdy and Beausoleil-Morrison 2001).

### 2.2.2 Uncertainty Analysis (UA)

Although uncertainty analysis and sensitivity analysis look similar, they are different. UA solves for uncertainty in y(x) given the uncertainty in x. SA determines how important the individual elements of x are with respect to the uncertainty in y(x) (Helton 2006).

Uncertainty can be separated into three areas (Hopfe et al. 2007; Hopfe and Hensen 2011). These three areas are:

1. Uncertainty in physical parameters: physical uncertainty is relative to the properties of the materials, for example, conductivity, thickness, and density.
2. Uncertainty in design parameters: this uncertainty comes from the planning process, which is completely decided by the decision maker/designer. For

example, this parameter includes the window’s location and all the elements relative to the design of the building.

3. Uncertainty in boundary: this uncertainty parameter includes the unpredicted factors. For example, weather, heat gain from the people inside the building, the natural ventilation controlled by the occupants etc.

From ASHRAE 14-2002 Guideline (ASHRAE 2002), the uncertainty in savings can be attributed to errors of assumptions, measurement errors, sampling errors and to errors in the regression model, which include predictive and normalization errors.

From UA and SA, we can test the robustness of a model (Litko 2005). We can also learn the most sensitive input parameter, allowing us to avoid errors when simulating the model (Hopfe et al. 2007). Additionally, the use of UA and SA allows us to have a better design for critical issues at the early design stages (Struck and Hensen 2006), e.g. energy consumption, energy cost and thermal comfort (Struck and Hensen 2006).

### 2.2.3 Methodologies for sensitivity analysis

The methods for sensitivity analysis for building energy performance can be divided into two categories: global sensitivity analysis and local sensitivity analysis (Tian 2013). Local sensitivity analysis is focused on the difference between the uncertainties caused by one input compared with the base model. In contrast, global sensitivity analysis is focused on the uncertainty caused by all inputs over the whole input space (Tian 2013).

Differential sensitivity analysis is a form of local sensitivity analysis. Global sensitivity analysis includes both Monte Carlo analysis and stochastic sensitivity analysis.

1. Differential sensitivity analysis (DSA) (Lomas and Eppel 1992)

   This method adjusts one input and keeps the remaining inputs the same with the baseline for each single simulation. This method has been used repeatedly in the field of building energy analysis (Tian 2013).

2. Monte Carlo analysis (MCA) (Lomas and Eppel 1992; Hopfe et al. 2007)

   This method adjusts all inputs randomly in each single simulation. A particular distribution will be developed after multiple simulations.

3. Stochastic sensitivity analysis (SSA) (Lomas and Eppel 1992)

   This method adjusts all inputs simultaneously for each simulation; however, the purpose of SSA is to detect a single parameter's sensitivity.

2.2.3.1 Drawbacks of local sensitivity analysis (Tian 2013)

Tian found three drawbacks of local sensitivity analysis. They are:

1. Only a limited input factor will be explored around base case.
2. This method cannot detect the interaction between each input factor.
3. There is no self-verification in this method.

2.2.3.2 Drawbacks of global sensitivity analysis

Since the Monte Carlo analysis requires changes to all the input parameters simultaneously, the sensitivity for each individual input cannot be detected. Like DSA, SSA will give the sensitivity for single inputs; however, it requires adjusting all the inputs at the same time. In this way, SSA is different from MCA and DSA, as it requires a complicated calculation (Lomas and Eppel 1992).

### 2.2.4 Steps of Sensitivity Analysis (Tian 2013)

#### 2.2.4.1 Input variations

The ranges of the inputs depend on the purpose of the sensitivity analysis. There are three different methods to establish the range of input values in Tian’s research.

1. Assess the energy performance in a new building using different design options.

   This is used for deciding the most energy efficient strategies for the project building. So the range for each input should not be restricted, and allowed to vary over all possible values.

2. Explore the variation of energy use in an existing building.

   The second range setting method is used for detecting the possible energy consumption variation of the project building and for determining the key variables causing this variation. The setting may also provide an answer for why the measured energy consumption data is different from the simulated energy consumption data for sensitivity analyzing the most sensitive inputs. In this case some of the inputs are fixed, such as the U-value of the wall, roof and windows. The reason for these input shifts may be due to the insulation quality, age of the building, lack of maintenance etc.

3. Perform the retrofit analysis for an existing building using different energy savings measures.

   This setting is focused on optimizing the energy consumption by the analysis of different input combinations. For example, use a different insulation thickness and other measures. The two-dimensional Monte Carlo method can be applied to this task, but it will be very complicated.

2.2.4.2 Steps to apply the sensitivity analysis experiment

After deciding how to choose the range, Tian recommends the following steps for performing the sensitivity analysis:

1. Run building energy models

   This step is always the most time-consuming part. It requires running simulated models created by building energy model software. The author gives two methods for reducing the simulation time: single computer with multicore or multiprocessor or multiple computers.

2. Adjust the input parameters to get the results

   This step is used for generating the data obtained from the multiple simulated models for adjusting the different input parameters.

3. Run sensitivity analysis

   Analyze the inputs and outputs based on the data collected from the step above.

4. Presentation of sensitivity analysis

The different ways to present sensitivity analysis are: scatter plot, tornado plot, box plot, and spider plot. Among these methods, scatter plot is particularly good at explaining the relationships between inputs and outputs.

### 2.2.5 Case study of ten air-conditioned buildings experiment (Lam 2008)

The building type for Lam's experiment is an office building. Ten of the key design parameters were chosen to fulfill the sensitivity analysis task. Perturbations were used to assign the range of different values for these 10 inputs. For analyzing the inputs and outputs, the influence coefficient (IC) was applied as the statistic method (Spitler et al. 1989).

$$IC = \frac{OP - OP_{bc}}{OP_{bc}} \div \frac{IP - IP_{bc}}{IP_{bc}} \qquad \text{Equation 2.3}$$

IC = Influence coefficient

OP = The output from the adjusted input case;

$OP_{bc}$= The output result with the base case input;

IP = Adjusted input;

$IP_{bc}$ = Base case input.

The influence coefficient is the ratio of the percentage change in computed output to the percentage change in the input design parameter.

After calibrating the building through DOE-2 simulation software, only one building in Lam's study does not meet the requirement of ASHRAE error criteria (i.e., 5% or less normal mean bias error and 15% or less root mean square error).

# 3. METHODOLOGIES

Two types of experiments have been conducted in this research: 1) the sensitivity analysis of input parameters using data produced by WinAM 4.3, and 2) the savings potential reliability analysis based on calibrated WinAM 4.3 models generated from CC® project reports.

## 3.1 Sensitivity analysis of WinAM's input parameters

In order to detect the input parameters' sensitivity of WinAM 4.3 software, the Differential Sensitivity Analysis (DSA) (Lomas and Eppel 1992) method was applied. DSA involves changing one parameter at a time while keeping the other parameters the same as the baseline. The statistical methods used include the Error Percentage (EP) and the Influence Coefficient (IC) (Spitler et al. 1989; Petr et al. 2007; Lam 2008). The purpose of this research was to identify sensitive parameters. That is parameters where a small change in the input has a large effect on the output. By identifying the sensitive parameters, WinAM users will have a better understanding of where to focus their efforts.

### 3.1.1 Create the baseline model

The baseline model that will be applied in this research is the square zone model. The building envelope information was taken from BESTEST CASE 600 (Henninger and Witte 2001). BESTEST CASE 600 has numerous detailed settings that cannot be applied to WinAM 4.3. For example, the Solar Heat Gain Coefficient (SHGC) of windows and the thermal mass of the wall are not considered in WinAM 4.3.

Input parameters that have been discussed in this report are : 1) outside air percentage, 2) interior zone percentage, 3) window and wall ratio, 4) minimum airflow ratio, 5) maximum airflow ratio, 6) zone temperature setpoint, 7) cooling coil temperature setpoint, 8) lighting loads, 9) fan power, 10) night plug load, 11) wall R-value, 12) window U-value, 13) roof U-value, and 14) occupancy.

3.1.2 HVAC system and inputs' information

The assumption was made that the user will make an error for each input parameter within $\pm$30%. The baseline model information is given in Table 3-1.

Seven models are created for each parameter: 30% model, 20% model, 10% model, $-$30% model, $-$20% model, $-$10% model and the baseline model.

For each model, the results for three energy recourse consumptions will be generated: electric energy consumption (this energy consumption only includes lighting, plug loads and fan power), chilled water consumption, and hot water consumption. Monthly and yearly consumption data will be generated separately. Monthly data is used for analyzing the sensitivity under different temperatures. Yearly data can give the parameter's yearly sensitivity.

In this research, the SDVAV system with and without the economizer will be studied. The weather data applied to this research is from Austin, Texas.

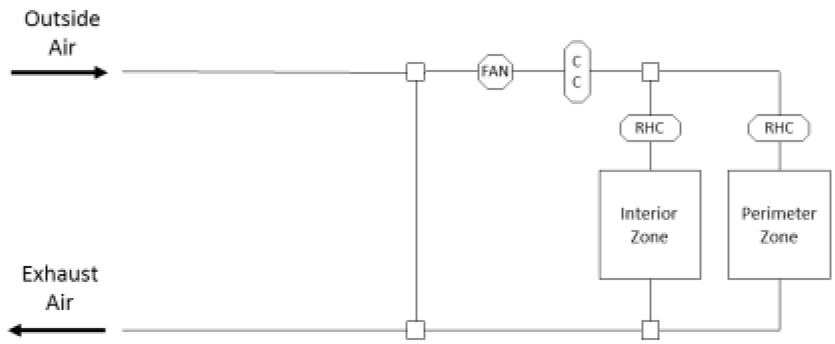



**Figure 3-1** SDVAV System in WinAM 4.3

Figure 3-1 shows the SDVAV system which has been used in this research. There is no preheating in this system. The supply fan is before the cooling coil and the reheat is configured for each zone.

**Table 3-1** Inputs for baseline model

| Parameters | Values |
|---|---|
| OA (outside air percentage) | 20% |
| IP (interior zone percentage) | 60% |
| W-W (window-wall ratio) | 30% |
| Min (minimum airflow rate) | 0.3 $\mathrm{CFM/ft^2}$ |
| Max (maximum airflow rate) | 1 $\mathrm{CFM/ft^2}$ |
| Tz (zone temperature) | 70°F |
| Tc (cooling coil temperature) | 50°F |
| Lighting (average lighting energy consumption) | 1 $\mathrm{W/ft^2}$ |
| Plug (average plug energy consumption) | 1 $\mathrm{W/ft^2}$ |
| Occ (peak occupancy) | 150 $\mathrm{ft^2/person}$ |
| FP (VAV fan power) | $1\,\frac{\mathrm{hp}}{1000}\,\mathrm{CFM}$ |

**Table 3-1** continued

| Parameters | Values |
|---|---|
| NLPL (nighttime lighting and plug load ratio) | 0.2 |
| Wall R (exterior wall R-value) | $12\ \frac{\mathrm{ft}^2*\mathrm{h}*°\mathrm{F}}{Btu}$ |
| Window U (exterior window U-value) | $0.75\ \frac{\mathrm{Btu}}{\mathrm{ft}^2}*\mathrm{h}*°\mathrm{F}$ |
| Roof U (roof U-value) | $0.048\ \frac{\mathrm{Btu}}{\mathrm{ft}^2}*\mathrm{h}*°\mathrm{F}$ |

Each parameter was adjusted to $\pm$10%, $\pm$20% and $\pm$30% compared with the parameter in the baseline model. The adjusted parameters are shown in Table 3-2.

Due to zone temperatures of 49°F (-30% compared with baseline model), 56°F (-20 compared with baseline model), and 91°F (-30% compared with baseline model) being outside of the acceptable input range setting in WinAM 4.3, these inputs will not be discussed here. This is the same reason for some of the inputs were not discussed for cooling coil temperature setpoint.

**Table 3-2** Adjusted Inputs

| Magnitude | −30% | −20% | −10% | 0% | 10% | 20% | 30% |
|---|---|---|---|---|---|---|---|
| OA (outside air percentage) | 0.14 | 0.16 | 0.18 | 0.2 | 0.22 | 0.24 | 0.26 |
| IP (interior zone percentage) | 0.42 | 0.48 | 0.54 | 0.6 | 0.66 | 0.72 | 0.78 |
| W-W (window-wall ratio) | 0.21 | 0.24 | 0.27 | 0.3 | 0.33 | 0.36 | 0.39 |
| Min (minimum airflow rate) | 0.21 | 0.24 | 0.27 | 0.3 | 0.33 | 0.36 | 0.39 |
| Max (maximum airflow rate) | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 1.3 |
| Tz (zone temperature) | ---- | ---- | 63 | 70 | 77 | 84 | ---- |
| Tc (cooling coil temperature) | ---- | 40 | 45 | 50 | 55 | 60 | 65 |

**Table 3-2** continued

| Magnitude | −30% | −20% | −10% | 0% | 10% | 20% | 30% |
|---|---|---|---|---|---|---|---|
| Lighting (average lighting energy consumption) | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 1.3 |
| FP (VAV fan power) | 0.7 | 0.8 | 0.9 | 1 | 1.1 | 1.2 | 1.3 |
| NLPL (nighttime lighting and plug load ratio) | 0.14 | 0.16 | 0.18 | 0.2 | 0.22 | 0.24 | 0.26 |
| Wall R (exterior wall R-value) | 8.4 | 9.6 | 10.8 | 12 | 13.2 | 14.4 | 15.6 |
| Window U (exterior window U-value) | 0.525 | 0.6 | 0.675 | 0.75 | 0.825 | 0.9 | 0.975 |
| Roof U (roof U-value) | 0.033 | 0.038 | 0.043 | 0.048 | 0.053 | 0.058 | 0.063 |
| Occ (peak occupancy) | 105 | 120 | 135 | 150 | 165 | 180 | 195 |

### 3.1.3 Statistical methods used for analyzing results

The analysis of the results has been divided into three parts.

1. Adjusted inputs impacts analysis.

   We analyzed monthly electric consumption, chilled water consumption and hot water consumption according to adjusted input parameters based on average monthly temperature. The purpose is to learn WinAM 4.3's input properties. Error Percentage (EP) has been used as the statistical method to assist in analyzing the results. The EP is the error of the adjusted case with respect to the base case.

$$\mathrm{EP} = \frac{\mathrm{A} - \mathrm{B}}{\mathrm{B}} * \ 100\% \qquad \text{Equation 3.1}$$

B = energy consumption data for base case;

A = energy consumption data for adjusted case.

2. Ranking the sensitivity of inputs based on warm and cold temperatures.

   The assumption is made that outside air temperature lower than 50˚F will be defined as a cold temperature, and outside air temperature higher than 70˚F is a hot temperature.

   Influence Coefficient (IC) will be used as the statistical method to analyze the results. The IC is the ratio of the percentage change in computed output to the percentage change in the input design parameter (Spitler et al. 1989). The Influence Coefficient was defined in Equation 2.3.

3. Input parameters' sensitivity ranking based on the whole year energy consumption.

   The Influence Coefficient (IC) statistical method was used to analysis the results in this step. This step differs from the previous step by using yearly data instead of monthly data.

### 3.2 Predicted savings potential reliability analysis

The predicted savings reliability analysis performed here compares the saving predicted by the simulated model generated from WinAM 4.3 CC® projects with the measured saving from CC® project reports.

3.2.1 Steps for establishing experiment

Figure 3-2 is the flowchart for the method used for the saving prediction task. Model a.*(* denote 1, 2, 3…) is the un-calibrated model, model b.* is the calibrated model.

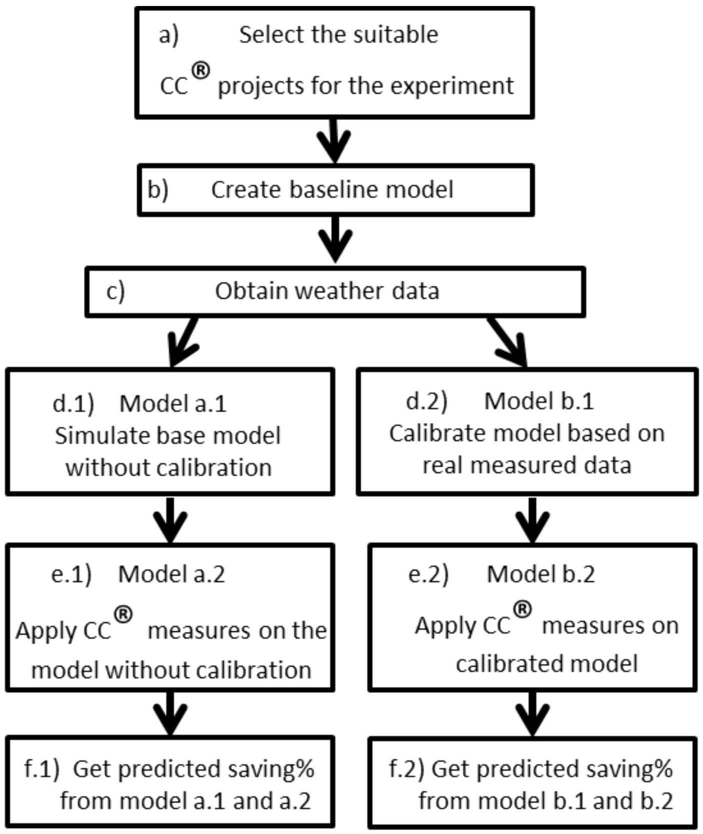



**Figure 3-2** Flowchart of savings prediction

3.2.1.1 Select suitable experiment subjects according to CC® reports

11 potential candidate CC® building projects were chosen to be experiment subjects. They are:

- Austin City Hall (ACH) (Zhou et. al 2009)
- Bayne-Jones Army Community Hospital (BJACH) (Bes-Tech Inc. and ESL 2009a)
- Blanchfield Army Community Hospital (BACH) (Bes-Tech Inc. and ESL 2009b)
- Fox Army Health Center (FAHC) (HHS Associates LLC and ESL 2009b)
- Martin Army Community Hospital ( MACH) (Effinger et al. 2008)
- North Business Tower of DFW International Airport (ESL 2010b)
- Rent-A-Car Center of DFW International Airport (Zeig et al. 2004)
- Sunset Valley Elementary School (SVES) (Yagua et al. 2009)
- Tripler Army Medical Center (TAMC) (HHS Associates LLC and ESL 2009a)
- Terminal D of DFW International Airport (ESL 2010a)
- Terminal E of DFW International Airport (ESL 2010c)

Included in the list are five hospitals, two airports, one city hall, one garage building, one office building and one K-12 building.

To be qualified as an experiment subject, the projects above needed to document the following information:

- System change for pre and post CC® measurements.
- Basic building and HVAC system information

  Take the Continuous Commissioning® Final Report for Bayne-Jones Army Community Hospital ( BJACH) 2009 as an example. This report documents the minimum airflow rate were set at 50% of maximum flow pre-CC® control, but there is no maximum airflow rate data  This report also lists four types of AHU systems but fails to give further information on the conditioned area of each AHU system.

After checking the CC® report for each project based on the criteria, seven projects were selected.

- Austin City Hall (ACH)
- Blanchfield Army Community Hospital (BACH)
- North Business Tower of DFW International Airport
- Rent-A-Car Center of DFW International Airport
- Sunset Valley Elementary School (SVES)
- Terminal D of DFW International Airport
- Terminal E of DFW International Airport

3.2.1.2 Create baseline model

The baseline model will be created based on the information documented in the Continuous Commissioning® reports.

The missing information required in inputs of WinAM 4.3 will be decided after a discussion with the engineer who performed or was familiar with the CC® project (the seven CC® projects mentioned in 3.2.1.1).  If the information cannot be obtained from any recode, the input will be decided based on the WinAM 4.3 help manual: how to use WinAM to calculate savings from energy conservation measures (ESL 2013a).

3.2.1.3 Obtain the weather data

The weather data will be generated from the CC®-Compass website created by the Energy Systems Laboratory (ESL. 2013b).

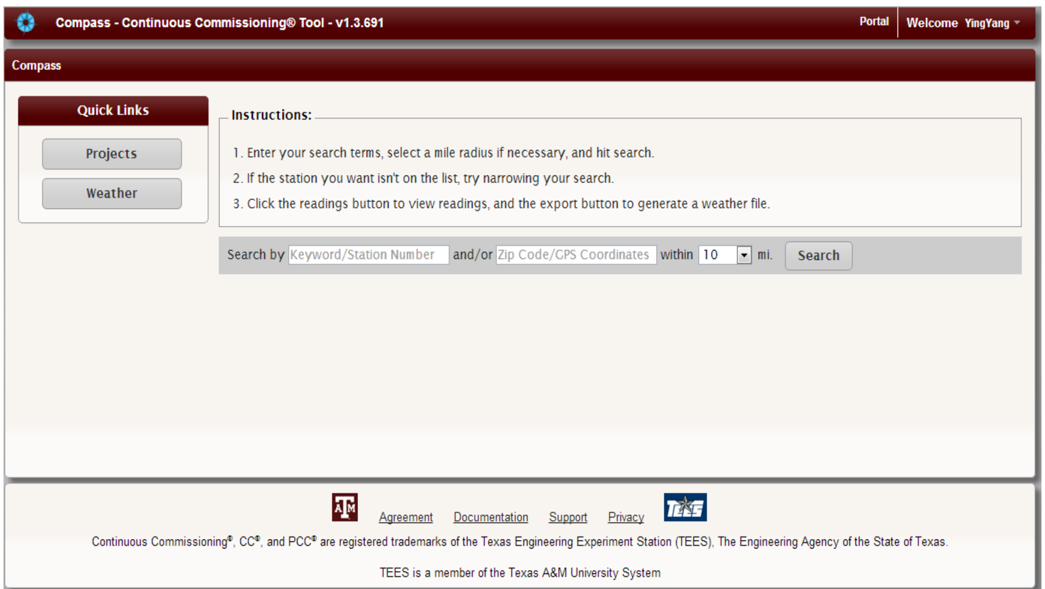


**Figure 3-3** Weather data tool from CC®-Compass (ESL. 2013b)

The steps for using the on-line weather tool shown in Figure 3-3 are as follows:

1. Enter search terms, select a mile radius if necessary, and press search.
2. If the weather station needed does not appear on the list, try expanding the search area.
3. Click the readings button to view readings, and the export button to generate a weather file.

For most models, the weather data will be obtained by taking above steps. Austin City Hall requires extra work to obtain its weather data, which is documented in Appendix A.

For testing the difference between WinAM4.3 and the similar building performance software, eQUEST 3.64 has been selected. eQUEST 3.64 uses typical meteorological year (TMY) weather data. It is not the real weather data for each year but the typical temperature to represent the weather phenomena for the certain location. Appendix A gives a detailed method on how to obtain the weather data. This method was used to obtain weather information for Austin City Hall.

3.2.1.4 Model simulation

1. Model a.1, simulated base model without calibration.

   The inputs for this model are obtained from the Continuous Commissioning® report. Some of the data not documented in the report came from the engineer who performed the CC® report or is imputed using the project average value.

2. Model b.1, calibrated model based on the real measured data.

   After creating Model a.1, the measured data was input into WinAM 4.3. With the help of the calibration assistant, the model was calibrated to the minimum error.

3.2.1.5 Apply CC® measures to the simulated model

1. Model a.2, CC® measures for model without calibration.

   Model a.2 is the model with CC® measures based on Model a.1. CC® measures applied in this step are obtained from the CC® reports.

2. Model b.2, CC® measures for model with calibration.

   Model b.2 is the model with CC® measures based on Model b.1. CC® measures applied in this step are obtained from the CC® reports.

3.2.1.6 Calculate savings

1. Calculate the predicted savings from Model a.1 and Model a.2.

   Calculate the energy savings percentage by using energy consumptions from Model a.1and the energy consumptions from Model a.2. The result should be calculated in dollars.

2. Calculate the predicted savings from Model b.1 and Model b.2.

   The method for this step is the same as the method to calculate the predicted savings from Model a.1 and Model a.2, the only difference is Model b.1 and b.2 were used instead of Model a.1 and a.2.

## 4. INPUTS' PROPERTIES ANALYSIS

This section focuses on the inputs analysis. Equation 4-1 to Equation 4-6 are important in understanding the physics of the phenomenon caused by adjusting the inputs.

$$Q_{cooling\ coil} = C * \dot{V} * \Delta T \qquad \text{Equation 4-1}$$

$$w_{fan} = w_{fan,max} * x_{fan} \qquad \text{Equation 4-2}$$

$$x_{fan} = plr^2 \qquad \text{Equation 4-3}$$

$$plr = \frac{\dot{V}}{\dot{V}_{max}} \qquad \text{Equation 4-4}$$

$$\Delta T_{fan} = \frac{SFP}{\rho c_p * a} \qquad \text{Equation 4-5}$$

$$\dot{Q} = \frac{\Delta T_{io}}{R} \qquad \text{Equation 4-6}$$

$Q_{cooling\ coil}$ = The cooling load on cooling coil, Btu/hr;

$C$ = Heat factor, $Btu/(hr * CFM * °F)$;

$\Delta T$ = Difference between the supply air temperature and the mixture air temperature, ˚F;

$w_{fan,max}$ = Fan's full load power;

$w_{fan}$ = Fan's real power;

$x_{fan}$ = The fraction of the fan's full load power;

$plr$ = The fraction of actual flow rate to maximum flow rate;

$\dot{V}$ = The actual flow rate, CFM;

$\dot{V}_{max}$ = The maximum flow rate, CFM;

$\Delta T_{fan}$ = Temperature across the fan, ˚F;

SFP = Specific fan power, kW/CFM;

$\rho$ = Density of the air, lbm/ft$^3$

$c_p$ = Specific heat of the air, $\mathrm{Btu/(lbm * R)}$;

a = Converts $\mathrm{Btu/hr}$ to Kw;

$\dot{Q}$ = Heat transfer rate, Btu/hr;

$\Delta T_{io}$ = Temperature difference between outside air temperature and zone temperature, °F;

R = Resistance of heat transfer, $\mathrm{(hr * °F)/Btu}[\frac{K}{W}]$.

**4.1 Outside air percentage (OA)**

The baseline for outside air percentage is 20%. Then, the baseline percentage needs to be adjusted from -30% to +30%. Thus, the inputs for the outside air percentage are: 14%, 16%, 18%, 20%, 22%, 24% and 26%. This is reflected in the legends in Figure 4-1 and Figure 4-2. The other charts in this section are presented in a similar way, with adjustment from $-30\%$ to $+30\%$ from the baseline value. Seven models will be created for analyzing the behavior of the outside air percentage parameter. In WinAM 4.3, this function has been named minimum OA percentage. Although it has been named as minimum, it will be a constant value in the system without the economizer.

The influence coefficients in Section 4 are calculated based on monthly data. After calculating the average influence coefficients, all these results will be reassigned based on the monthly average temperature from low to high.

4.1.1 Electricity

The electricity in this section only includes the fan power and the lighting/plug loads. If the lighting/plug loads do not change, fan power is the only variable to decide whether the electricity will be changed or not. For the VAV system, fan power will be affected by the cooling and heating loads. When adjusting the outside air percentage from 14% to 26%, no change occurred in electricity. This means when adjusting outside air percentage within ±30% based on the original setting are not causing the fan to work more or work less in this model.

4.1.2 Chilled water

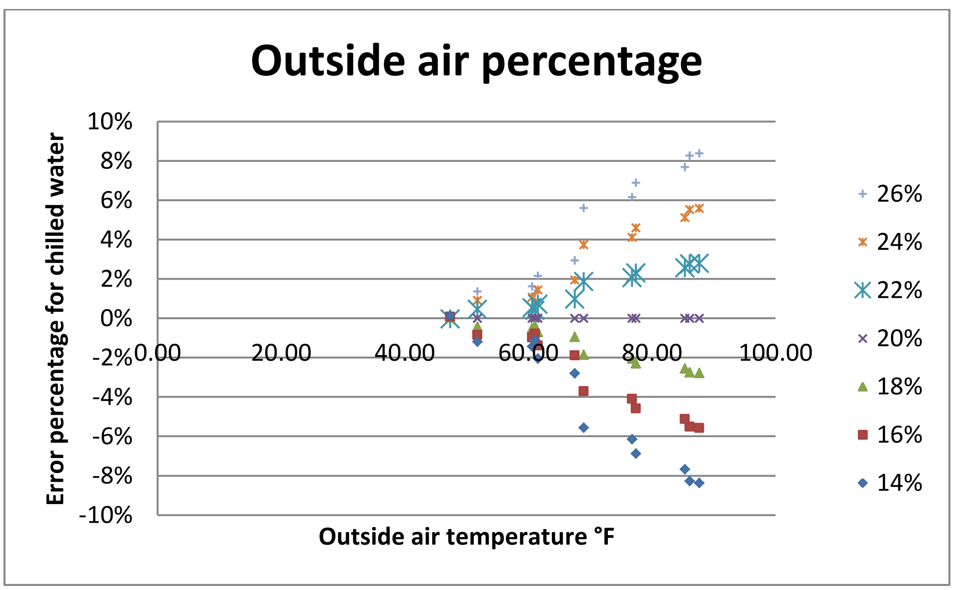



**Figure 4-1** Chilled water consumption for the OA% parameter, SDVAV with the economizer

Figure 4-1 shows the chilled water consumption difference percentage of the SDVAV system with the economizer. The temperature economizer range in this experiment is from 30˚F to 60˚F. If the system has the economizer, when outside air temperature (OAT) is between 30˚F and 60˚F, free cooling will be used. The chart implies that when increasing the outside air percentage, the chilled water consumption will be increased. This effect is more obvious when the outside air temperature is high. Under hot OATs, when the outside air volume percentage is increased, the mixed air temperature will be increased. From Equation 4-1, when the fan power does not change, more chilled water will be required to meet the cooling requirement from the cooling coil.

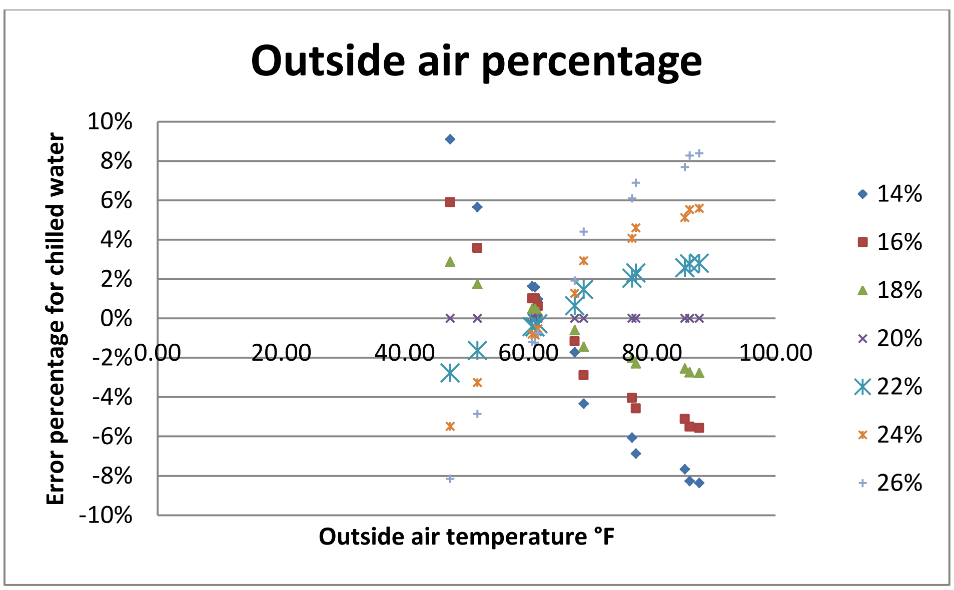
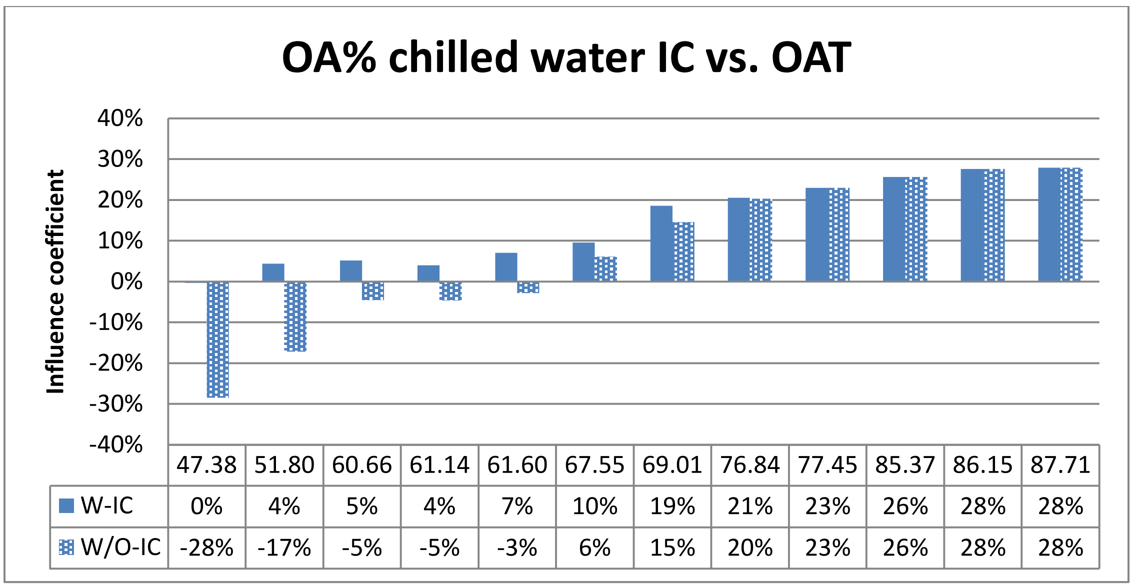



**Figure 4-2** Chilled water consumption for the OA% parameter, SDVAV without the economizer

Figure 4-2 shows the chilled water consumption difference percentage of the SDVAV system without the economizer. The chilled water consumption will be decreased when increasing the OA percentage in cold OATs. This is because the minimum OA percentage keeps the OA percentage at input value. So even in the cold OATs the system does not require that much outside air.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 0% | 4% | 5% | 4% | 7% | 10% | 19% | 21% | 23% | 26% | 28% | 28% |
| W/O-IC | -28% | -17% | -5% | -5% | -3% | 6% | 15% | 20% | 23% | 26% | 28% | 28% |

**Figure 4-3** Chilled water consumption IC value for the parameter OA%

Figure 4-3 shows the influence coefficient for both systems with and without the economizer. $\mathrm{W-IC}$ represents the influence coefficient of the system with the economizer, and $\mathrm{W/O-IC}$ represents the influence coefficient of the system without the economizer. This figure shows that the SDVAV system without the economizer is more sensitive when the monthly average outside air temperature (OAT) is below 61.6˚F. The influence coefficients should be equal between both systems when the average temperature is higher than 60˚F, because the free cooling temperature range for the economizer is between 30 ˚F to 60 ˚F. The reason for the difference is that the temperature used here is the monthly average temperature. That means although the mean temperature is higher than 60˚F (the economizer should not be operated), the daily temperatures in this month can be lower than 60˚F which means the economizer still work sometimes in this month even if the average monthly OAT is higher than 60˚F.

### 4.1.3 Hot water

This experiment shows that the hot water will not be impacted by adjusting the outside air percentage parameter for the SDVAV system with or without the economizer. This is because the required supply airflow rate does not change, so the supply air from the cooling coil is always at 55 ˚F. Consequently the hot water consumption is always the same.

## 4.2 Interior zone percentage (IP)

Figure 4-4 shows how WinAM 4.3 assigns the interior zone and the exterior zone. The darker color represents the exterior zone and the lighter color represents the interior zone.

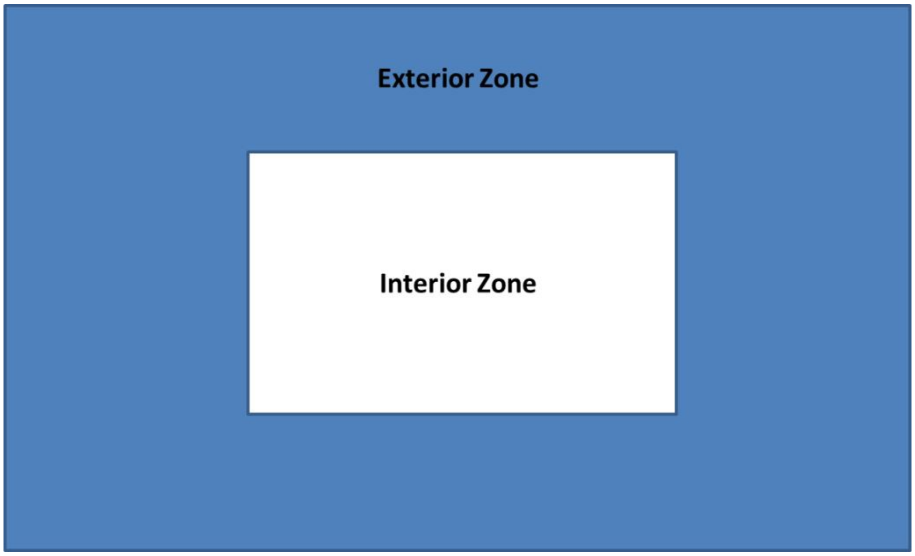


**Figure 4-4** Interior zone and exterior zone

Loads of the interior zone are only affected by lighting/plug and occupancy loads in WinAM 4.3. In WinAM 4.3, loads in the exterior zone will also be affected by outside air temperature.

The results for electric consumption, chilled water consumption and hot water consumption are the same for the SDVAV system with and without the economizer.

4.2.1 Electricity

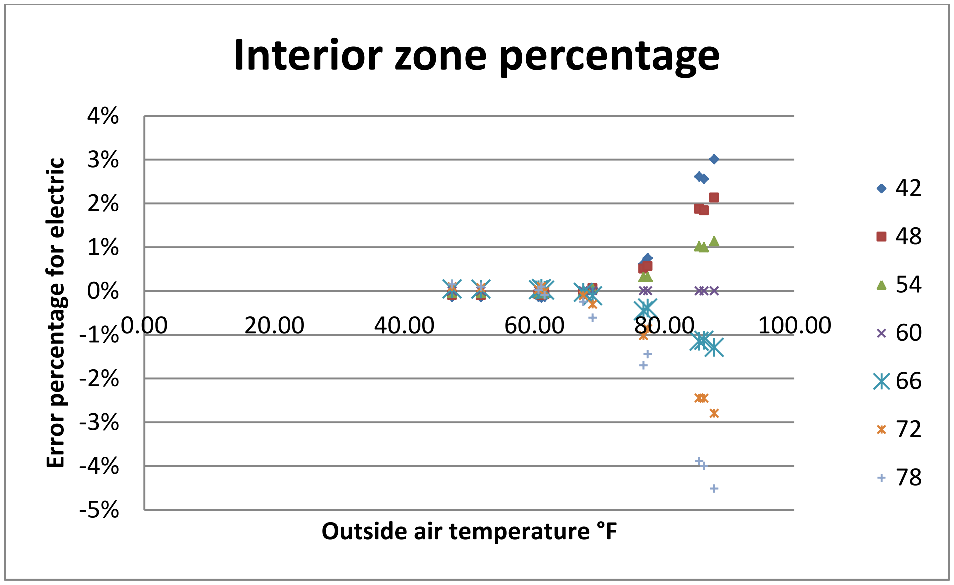



**Figure 4-5** Electric consumption for the parameter IP , SDVAV without the economizer

When the interior zone percentage is reduced, electric consumption will be increased, Figure 4-5. That means the fan needs to do more work to keep the zone temperature at its setpoint. As discussed before, the reason for that is because more area will be affected by outside air temperature. The effect on electricity caused by the interior percentage parameter is more sensitive in hot OATs. The electric consumption difference percentage is the same for the system with and without the economizer. This can be proved by the influence coefficients from both systems shown in Figure 4-6.

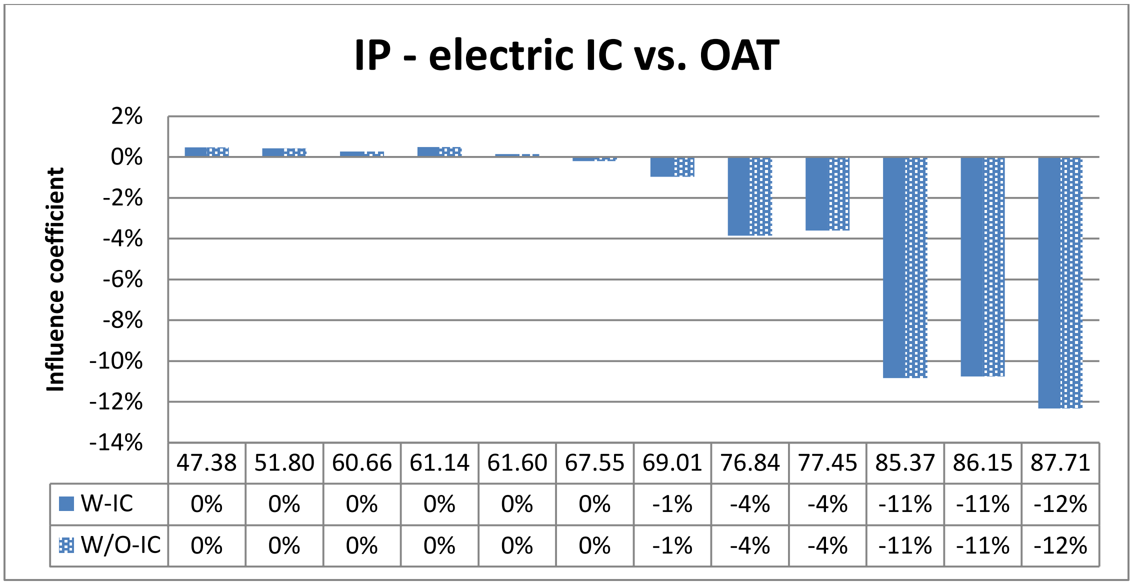



**Figure 4-6** Electric consumption IC value for the parameter IP

4.2.2 Chilled water

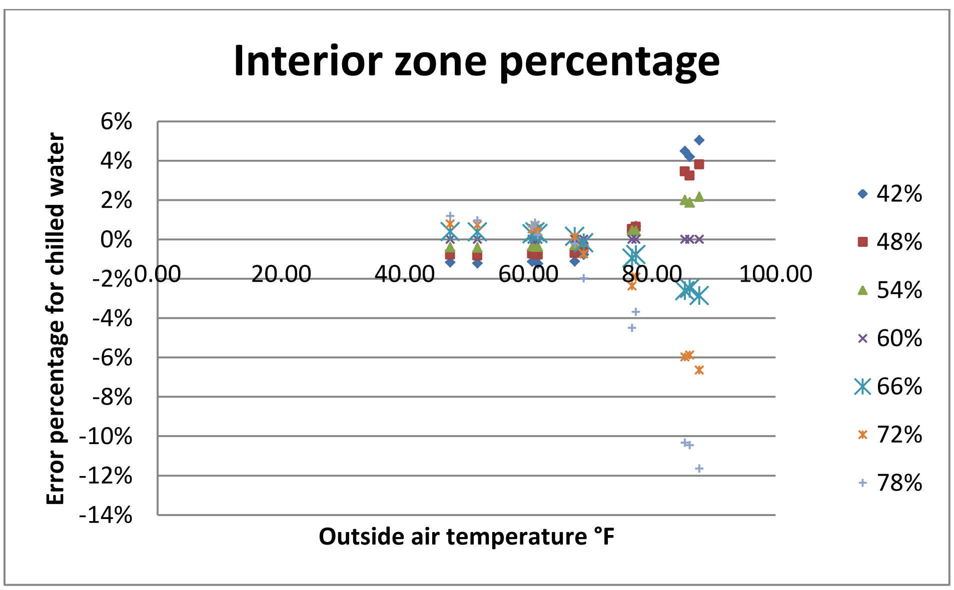



**Figure 4-7** Chilled water consumption for the parameter IP when SDVAV without the economizer

The patterns of error percentage results of chilled water consumption are shown in Figure 4-7. When the interior zone percentage is increased, less chilled water will be consumed. This is because the interior zone load isn't impacted by outside air temperature, so the chilled water consumption for the interior zone mainly depends on the temperature across the fan, the lighting plug loads and the occupancy. Under this condition, the larger the exterior zone is the more area will be affected by outside air temperature. The chilled water consumption influence coefficients in Figure 4-8 shows that the effect of the interior percentage parameter is almost the same for both the system with and the system without the economizer.

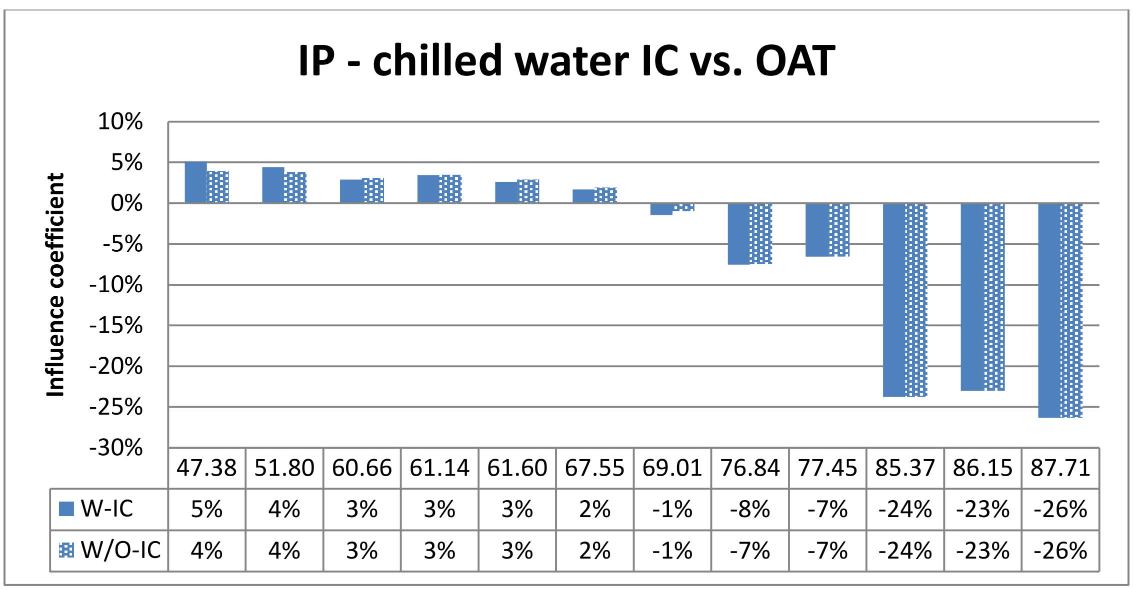



**Figure 4-8** Chilled water consumption IC value for the parameter IP

4.2.3 Hot water

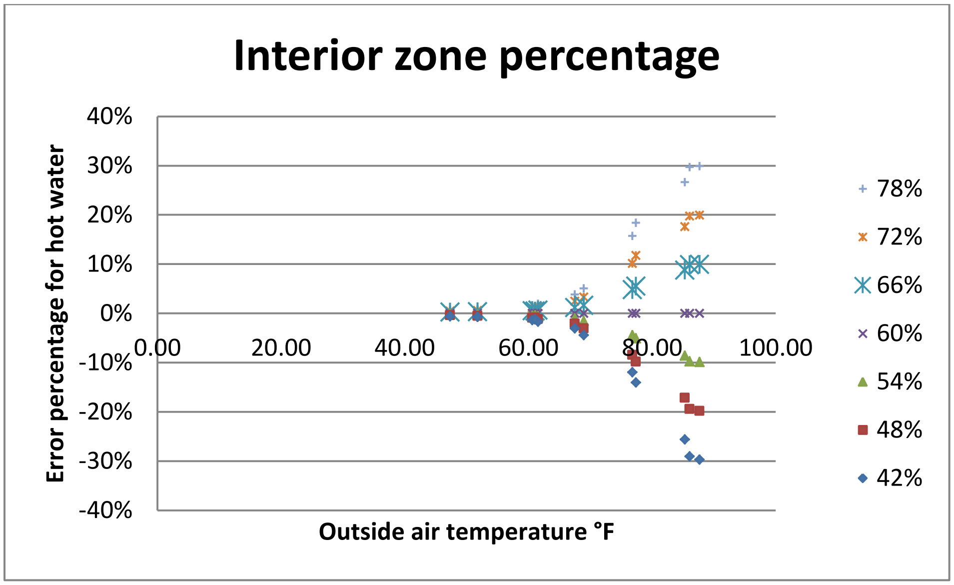
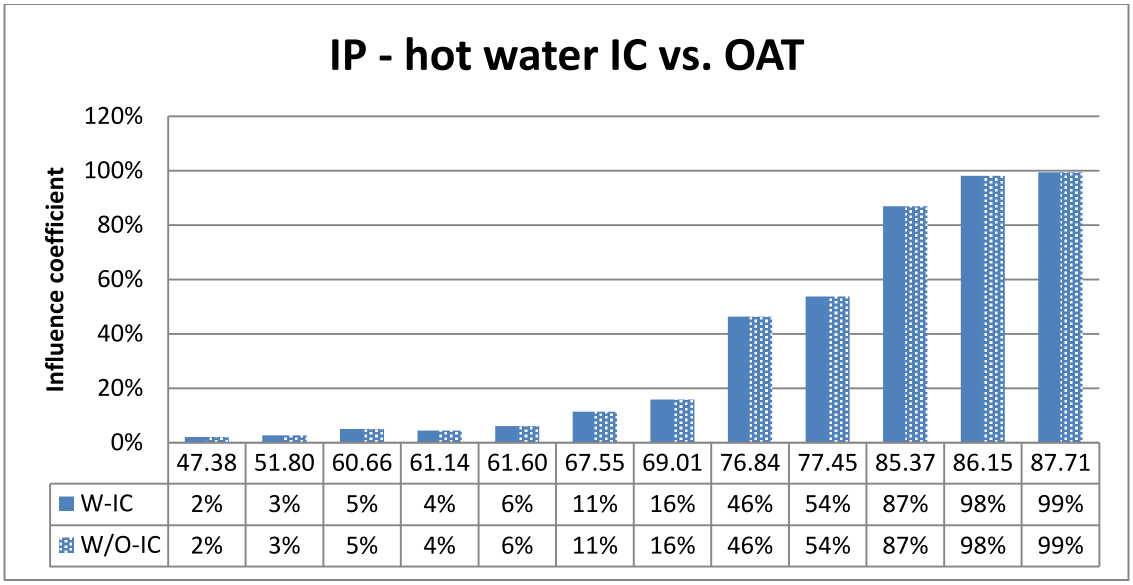



**Figure 4-9** Hot water consumption for the parameter IP, SDVAV without the economizer

For the SDVAV system with and without the economizer, Figure 4-9 shows that when the interior percentage is reduced, the hot water consumption will be reduced. This is more sensitive in hot OATs.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 2% | 3% | 5% | 4% | 6% | 11% | 16% | 46% | 54% | 87% | 98% | 99% |
| W/O-IC | 2% | 3% | 5% | 4% | 6% | 11% | 16% | 46% | 54% | 87% | 98% | 99% |

**Figure 4-10** Hot water consumption IC value for the parameter IP

Figure 4-10 shows that the influence coefficients are the same for both systems, and it is more sensitivity in the hot weather.

### 4.3 Window-wall ratio (W-W)

In WinAM 4.3, the window only has a U-value. Adjusting the window-wall ratio here will only result in changing the average U-value of the wall. A similar situation will happen to the window U-value parameter also.

4.3.1 Electricity

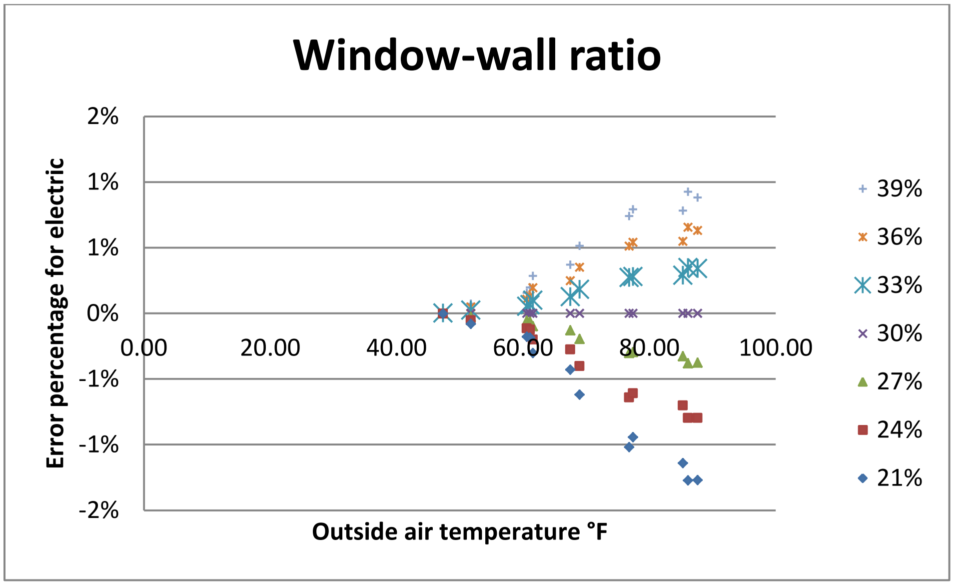



**Figure 4-11** Electric consumption for the parameter W-W, SDVAV with the economizer

Figure 4-11 shows that when the window-wall ratio is reduced, the electric consumption usage will be reduced too. This parameter is more sensitive in the hot OATs for electric consumption and it can be explained as the U-value of the wall will be reduced or increased if enlarging or decreasing the area of the window. When the U-value of the wall is increased, the insulation of the wall is reduced at the same time. A wall with a higher U-value is not as good as a wall with a lower U-value in keeping the building temperature constant. In this condition, the fan needs to do more work to keep the zone temperature at its setpoint.

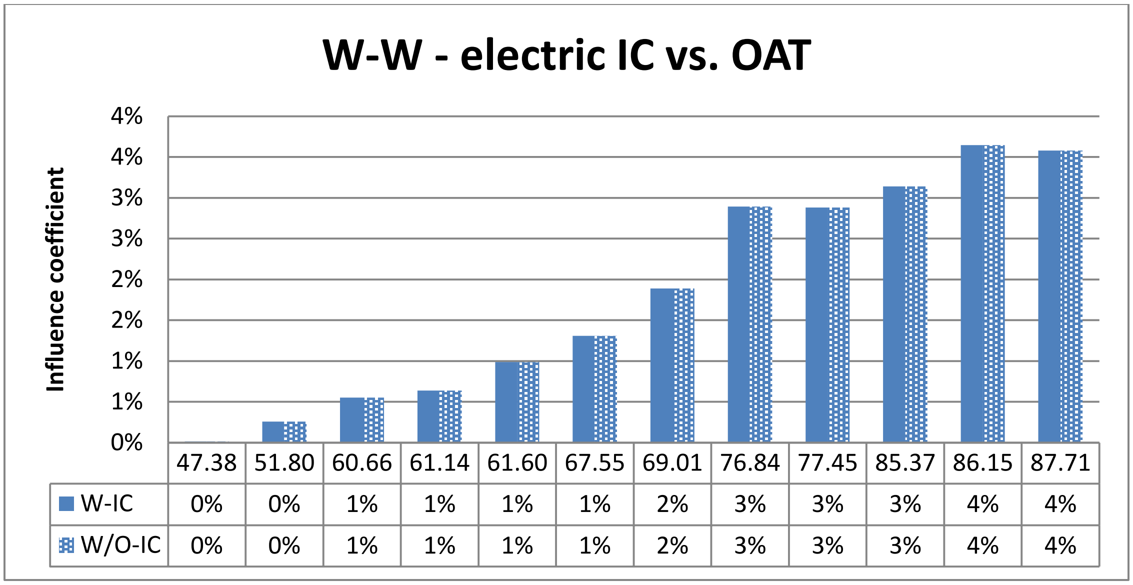


**Figure 4-12** Electric consumption IC value for the parameter W-W

Figure 4-12 shows the window-wall influence coefficients are the same for the system with and without the economizer, and it is more sensitive for electric consumption in the hot OAT.

4.3.2 Chilled water

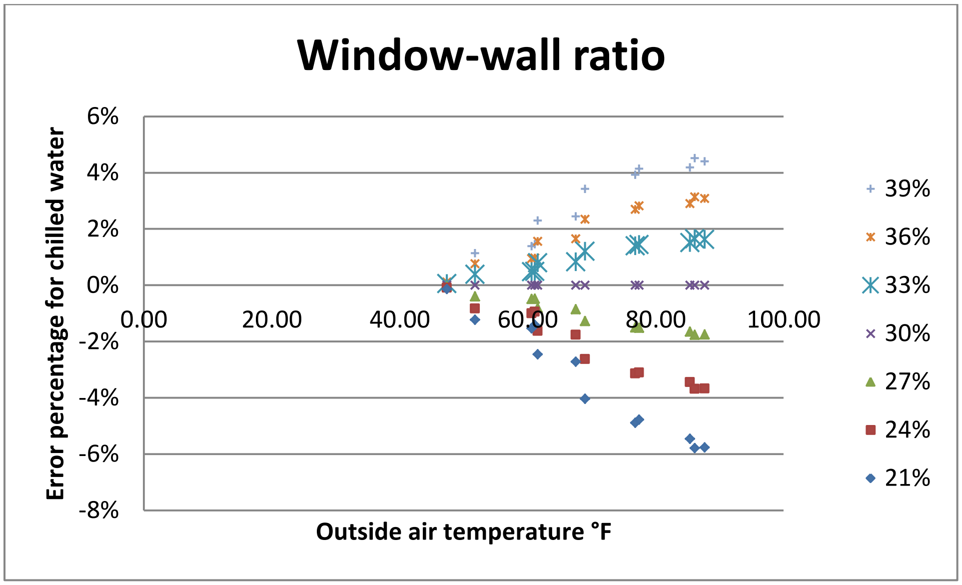


**Figure 4-13** Chilled water consumption for the parameter W-W, SDVAV with the economizer

The reason for the result of chilled water consumption difference percentage shown in Figure 4-13 is that the zone needs to be cooled throughout the year. The physics are the same as for electric consumption.

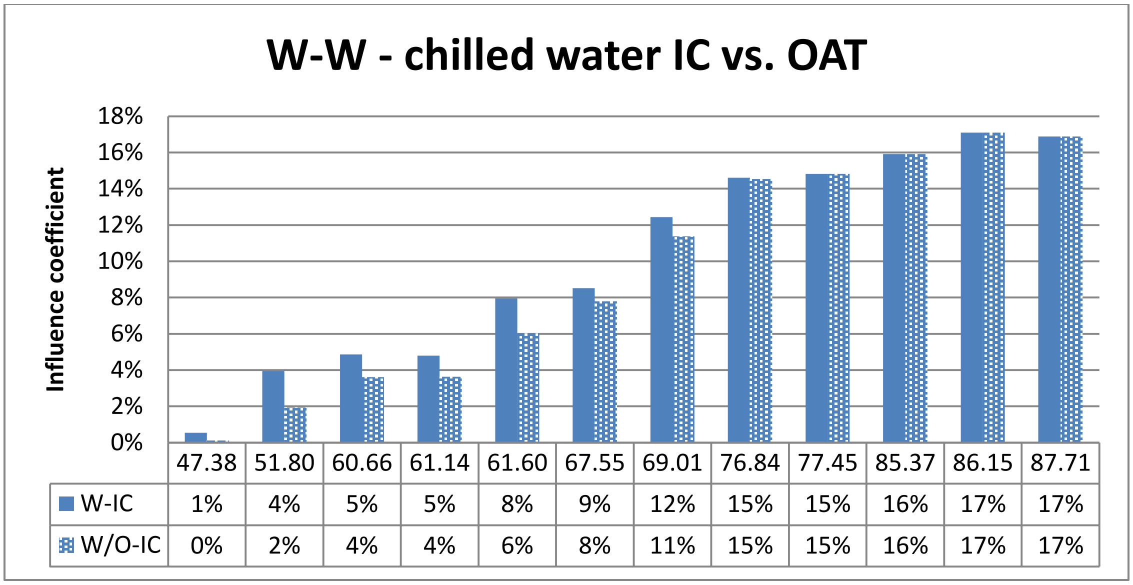



**Figure 4-14** Chilled water consumption IC value for the parameter W-W

The window-wall ratio parameter is sensitive to the system with the economizer under the cold OATs, Figure 4-14. Because of the free cooling, the economizer uses less chilled water.

### 4.3.3 Hot water

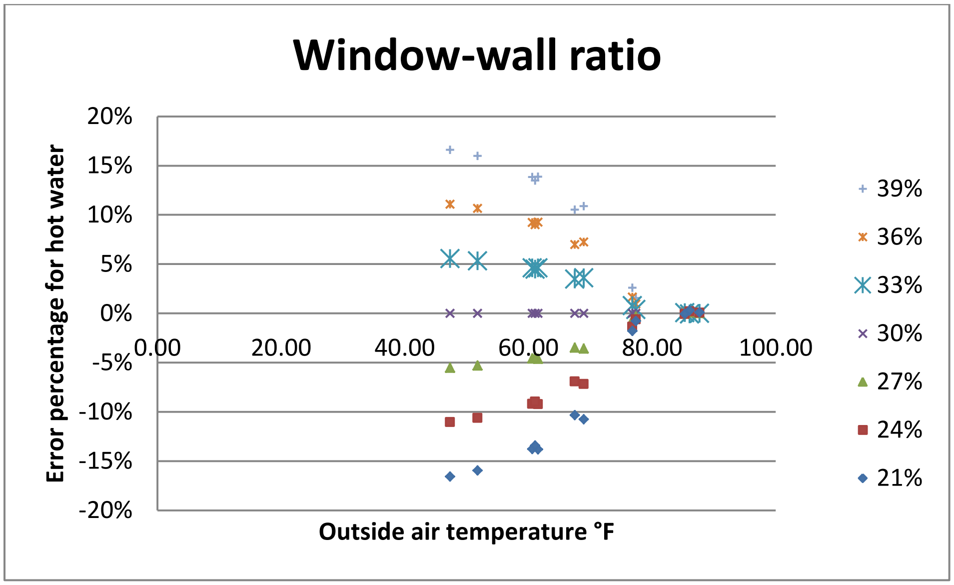



**Figure 4-15** Hot water consumption for the parameter W-W SDVAV with the economizer

When reducing the window-wall ratio, the hot water consumption is reduced, as shown in Figure 4-15. This phenomenon is easy to explain. The thermal resistance ability has been reduced, so the project zone's ability for keeping warm has been reduced, which means the system needs more hot water to keep the zone warm.

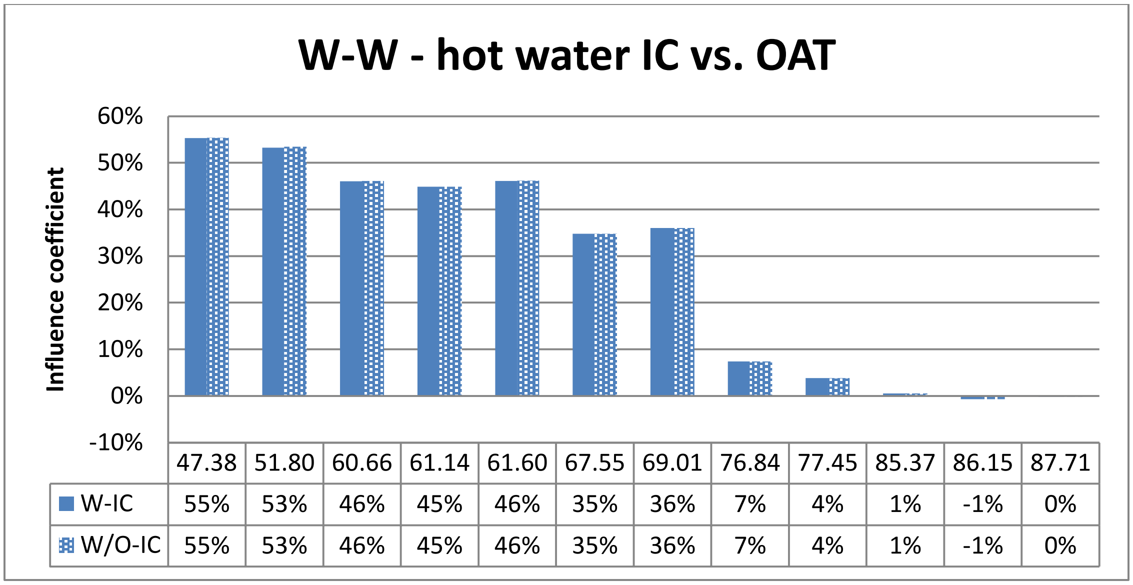



**Figure 4-16** Hot water consumption IC value for the parameter W-W

Figure 4-16 shows that the hot water influence coefficients are higher in cold weather than hot weather which is caused by the window-wall ratio parameter. This means that the hot water consumption is more sensitive to the window-wall ratio parameter in cold weather.

### 4.4 Minimum airflow rate (Min)

The units for minimum airflow rate parameter in this research is cubic feet per minute per square foot.

4.4.1 Electricity

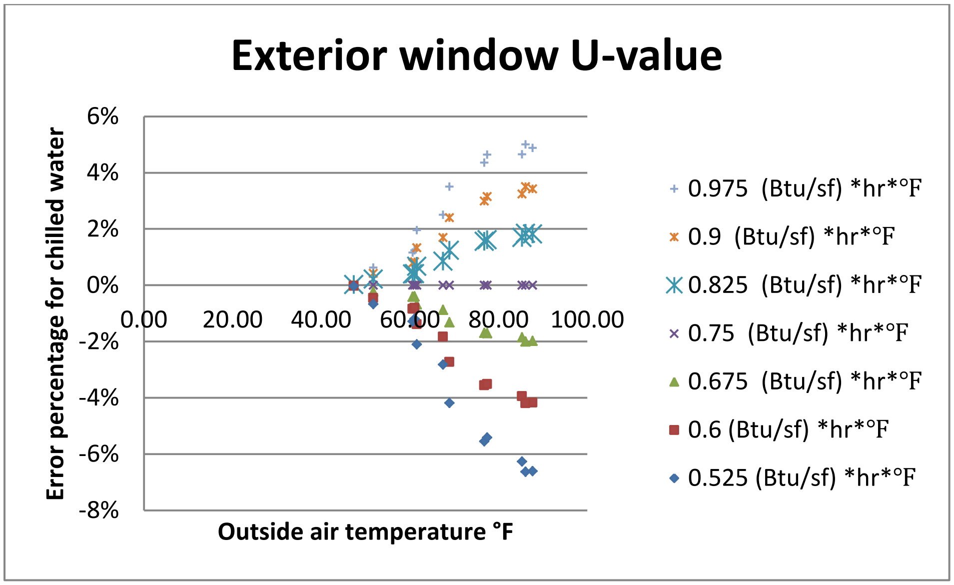
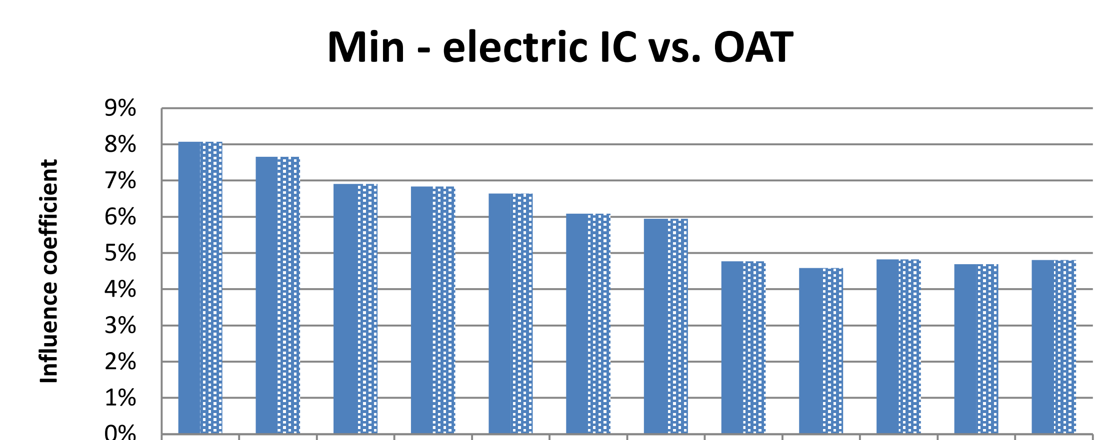



**Figure 4-17** Electric consumption for the parameter Min, SDVAV without the economizer

Figure 4-17 shows that when the minimum airflow rate is reduced, the electric consumption will be reduced. And electric consumption is more sensitive to this parameter in cold weather. An example follows to explain this phenomenon. The minimum airflow rate is 0.3 CFM/ft$^2$ for the base case, but the zone only requires a 0.1 CFM/ft$^2$ minimum flow rate. If the engineer reduces the minimum airflow rate from 0.3 CFM/ft$^2$ to 0.2 CFM/ft$^2$, although 0.2 CFM/ft$^2$ is not the perfect minimum airflow rate, the fan requires less power than at the 0.3 CFM/ft$^2$ setting.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 8% | 8% | 7% | 7% | 7% | 6% | 6% | 5% | 5% | 5% | 5% | 5% |
| W/O-IC | 8% | 8% | 7% | 7% | 7% | 6% | 6% | 5% | 5% | 5% | 5% | 5% |

**Figure 4-18** Electric consumption IC value for the parameter Min

Figure 4-18 shows that the sensitivity of the minimum airflow rate parameter is the same for both the SDVAV system with the economizer and without the economizer.

4.4.2 Chilled water

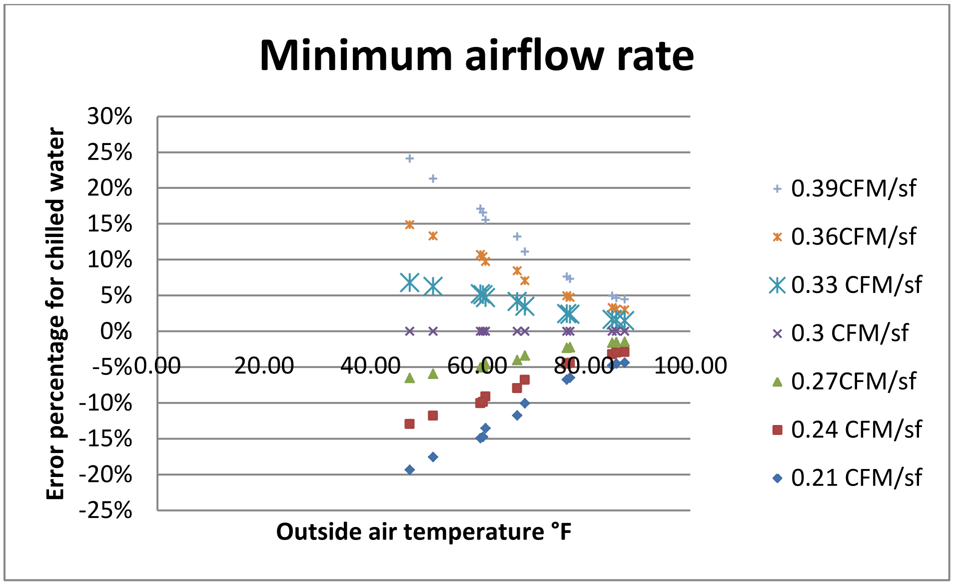



**Figure 4-19** Chilled water consumption for the parameter Min, SDVAV without the economizer

Figure 4-19 implies that the chilled water consumption difference percentage will be reduced when the minimum airflow rate is decreased. The reason is similar to the electric consumption. When decreasing the minimum airflow rate, the system can save energy when it does not need to offer that much cooling.

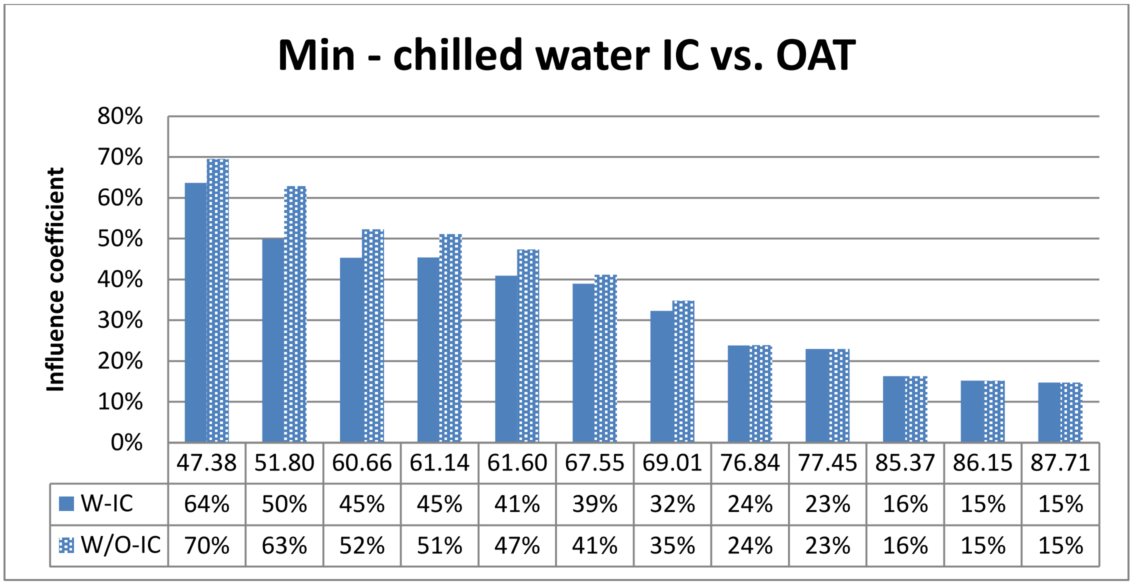



**Figure 4-20** Chilled water consumption IC value for the parameter Min

Figure 4-20 shows that in cold OATs the system with the economizer is less sensitive to the minimum airflow rate parameter than the system without the economizer.  This is because the system with the economizer can get free cooling from the outside air.  In this way, the chilled water consumption will not be changed as much as its consumption for the system without the economizer.

### 4.4.3 Hot water

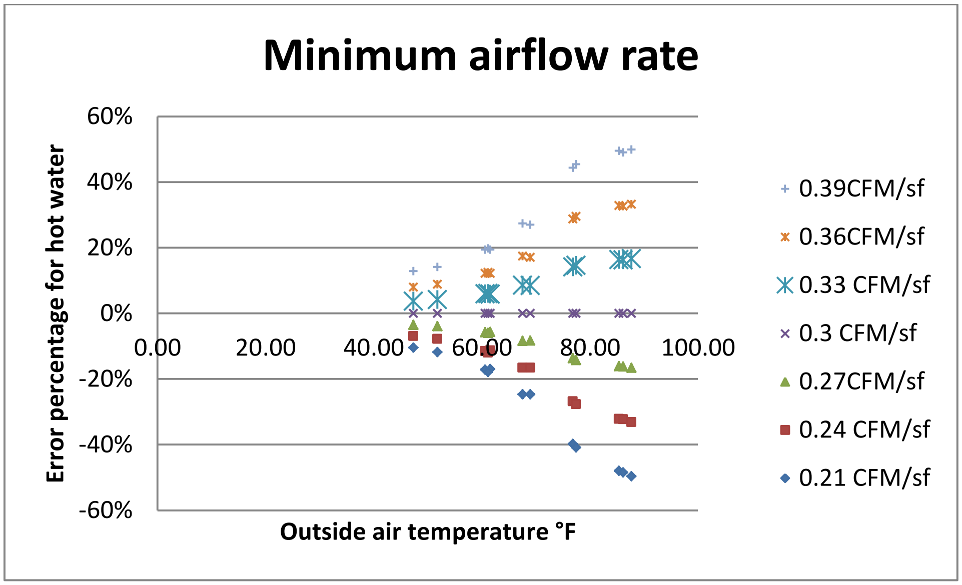



**Figure 4-21** Hot water consumption for the parameter Min, SDVAV without the economizer

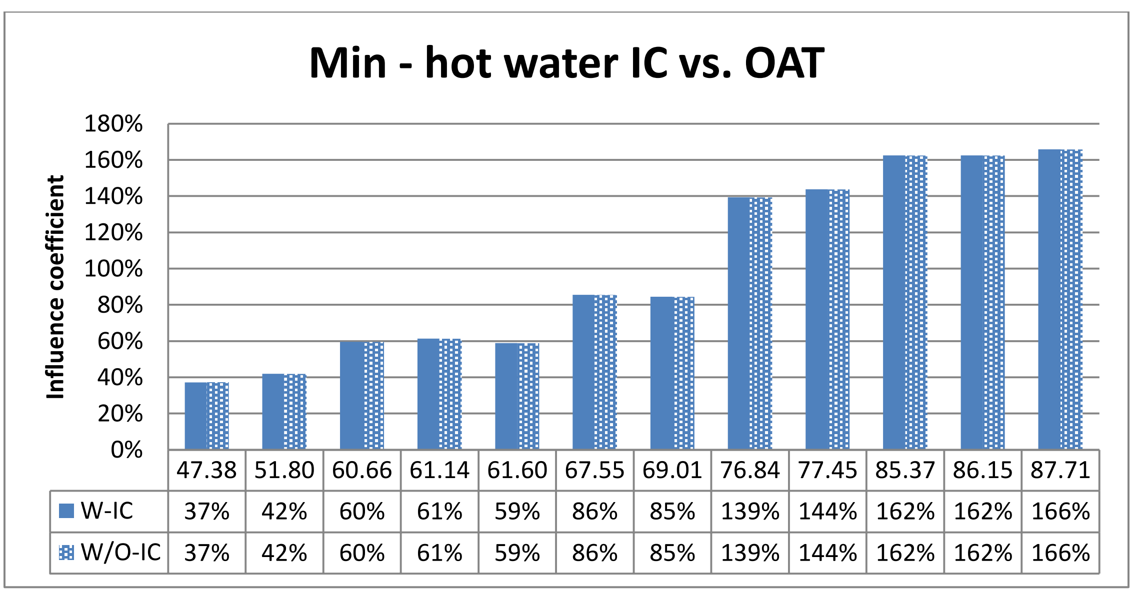



**Figure 4-22** Hot water consumption IC value for the parameter Min

Figure 4-21 and Figure 4-22 show the impact of hot water consumption caused by adjusting the minimum airflow rate parameter. This impact is opposite that of electric and chilled water consumption. The reason is that in cold OATs the hot water will be consumed more to balance the heat loss in the cold weather. Under this condition, for example, system A needs to pump the same amount of extra hot water when increasing the minimum air volume to keep the zone temperature at its setpoint. The minimum airflow rate for system A is 0.3 CFM. In the cold weather, system A needs 3 $\frac{\text{gallon}}{\text{minute}}$ of hot water to keep the zone temperature at its setpoint, and needs 2 $\frac{\text{gallon}}{\text{minute}}$ of hot water in hot weather.

### 4.5 Maximum airflow rate (Max)

4.5.1 Electric

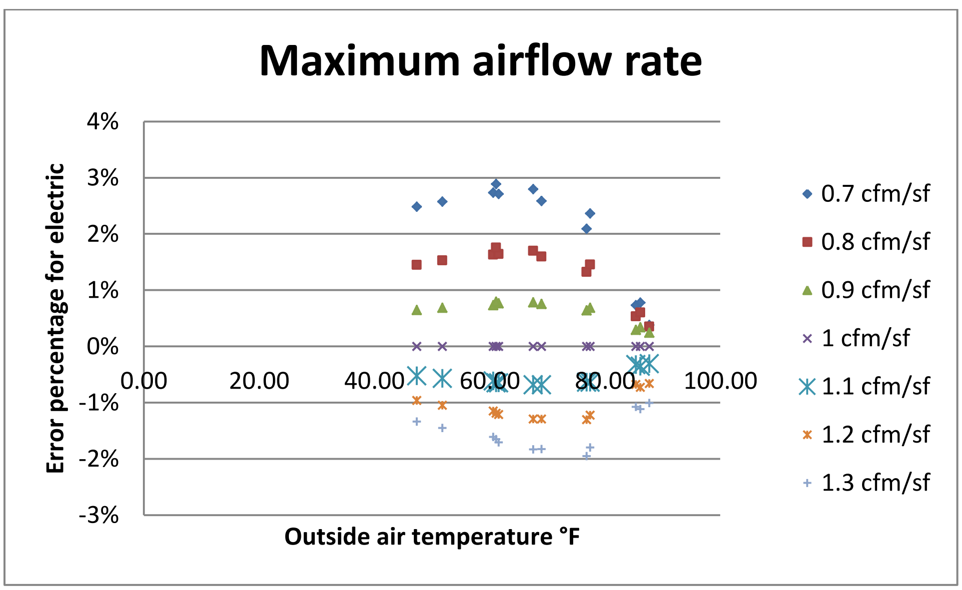
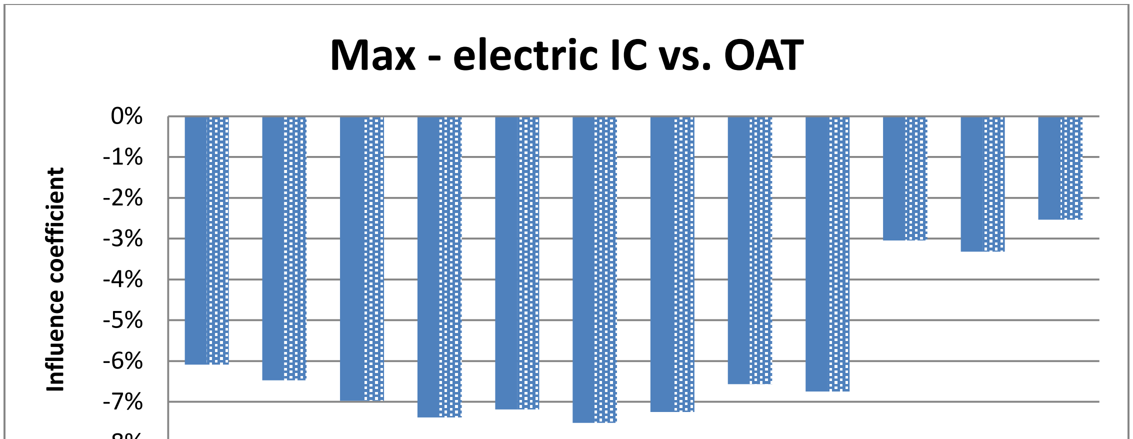



**Figure 4-23** Electric consumption for the parameter Max, SDVAV with the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | -6% | -6% | -7% | -7% | -7% | -8% | -7% | -7% | -7% | -3% | -3% | -3% |
| W/O-IC | -6% | -6% | -7% | -7% | -7% | -8% | -7% | -7% | -7% | -3% | -3% | -3% |

**Figure 4-24** Electric consumption IC value for the parameter Max

Figure 4-23 and Figure 4-24 show the maximum airflow rate parameter for electric consumption is more sensitive in the range of average monthly OAT: 47˚F to 78˚F. This parameter effect is the same for the systems with and without the economizer. The electric consumption is increased when the maximum airflow rate is decreased. The reason for this can be explained with the following example. Suppose the requirement for maintaining the zone temperature at its setpoint when the outside air temperature is 80˚F is that the maximum airflow rate for the system is 1CFM/ft$^2$. When the maximum airflow rate is decreased, the zone temperature cannot be kept at its setpoint. That is why when the maximum airflow rate decreases, the electric consumption will increase.

4.5.2 Chilled water

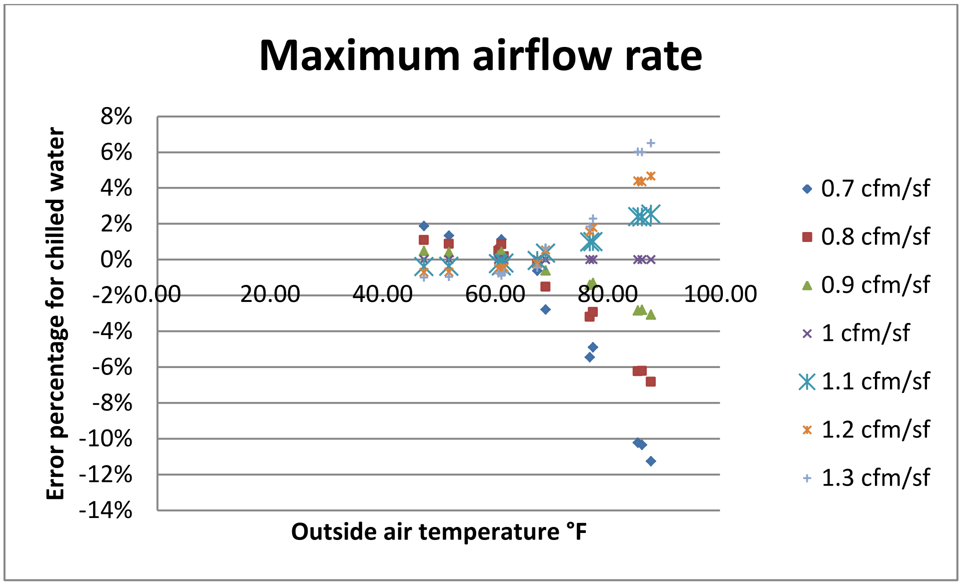



**Figure 4-25** Chilled water consumption for the parameter Max, SDVAV with the economizer

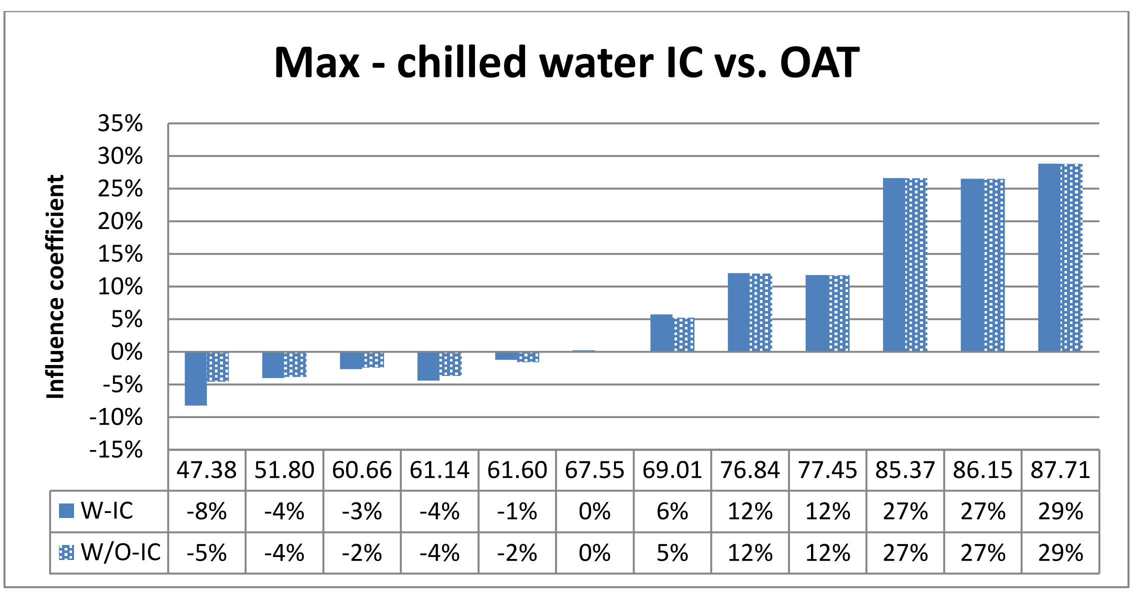



**Figure 4-26** Chilled water consumption IC value for the parameter Max

Figure 4-25 shows when the average monthly OAT is below 61.6˚F (include 61.6˚F). The maximum airflow rate parameter effect of chilled water consumption for both systems with and without the economizer is the same in hot weather, while the effect is more sensitive in cold weather for the system with the economizer, Figure 4-26. Decreasing the maximum airflow rate, the chilled water consumption will increase. When the outside air temperature is higher than 61.6˚F, decreasing the maximum airflow rate will cause the chilled water consumption to decrease. The reason for that can be explained by the fan model used in WinAM 4.3.

When reducing the maximum flow rate, the fraction of the fan's full load power will be increased if the required flow rate does not change. Under this condition, the fan power will be increased. When the fan power is increased the temperature across the fan will also be increased. More chilled water is required to cool down the increased temperature that is caused by the fan. This is the reason that when the maximum airflow rate is decreased the chilled water consumption will be increased.

4.5.3 Hot water

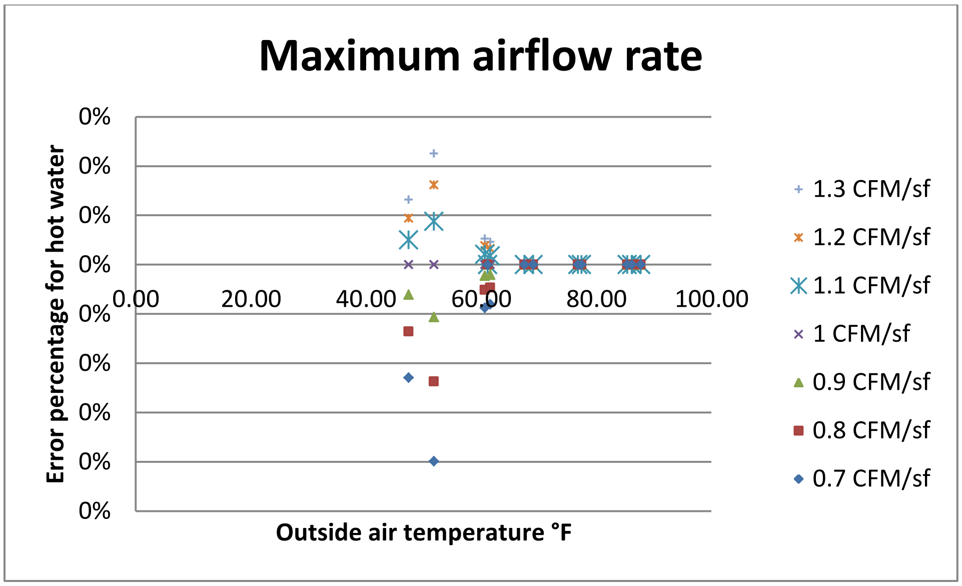



**Figure 4-27** Hot water consumption for the parameter Max, SDVAV with the economizer

Figure 4-27 shows that the maximum airflow rate influence coefficients for hot water consumption are almost zero for the system with the economizer and the system without the economizer. Therefore, the effect of this parameter on hot water consumption can be ignored.

## 4.6 Zone temperature (Tz)

4.6.1 Electric

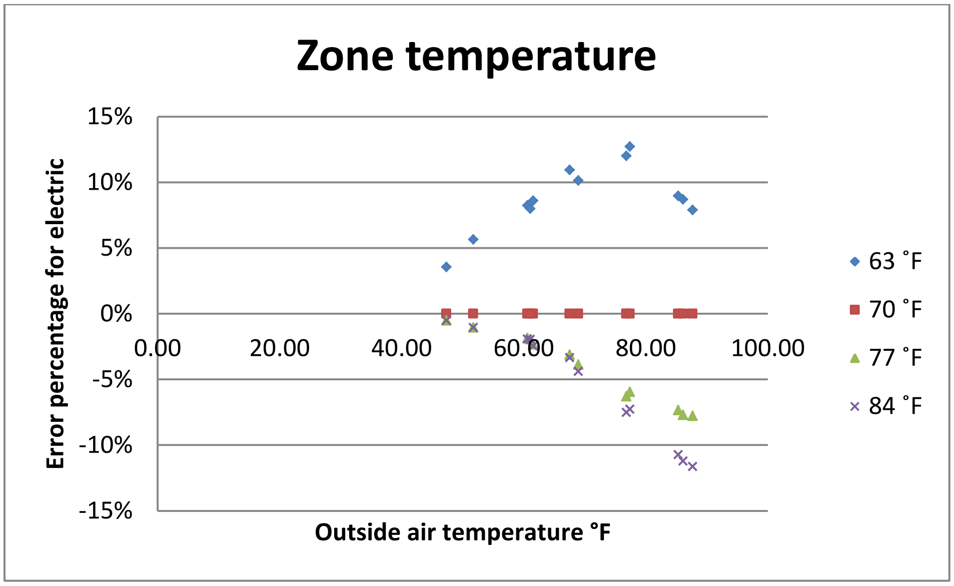



**Figure 4-28** Electric consumption for the parameter Tz, SDVAV with the economizer

Figure 4-28 shows that the electric consumption will be increased if the zone temperature setpoint decreases. The cooling coil temperature will not be changed, so for achieving the lower zone temperature setpoint, the fan needs to work harder. The peak of the curve in Figure 4-28 means the fan is at its maximum speed. Under this condition when OAT keeps increasing, the fan will keep constant speed.

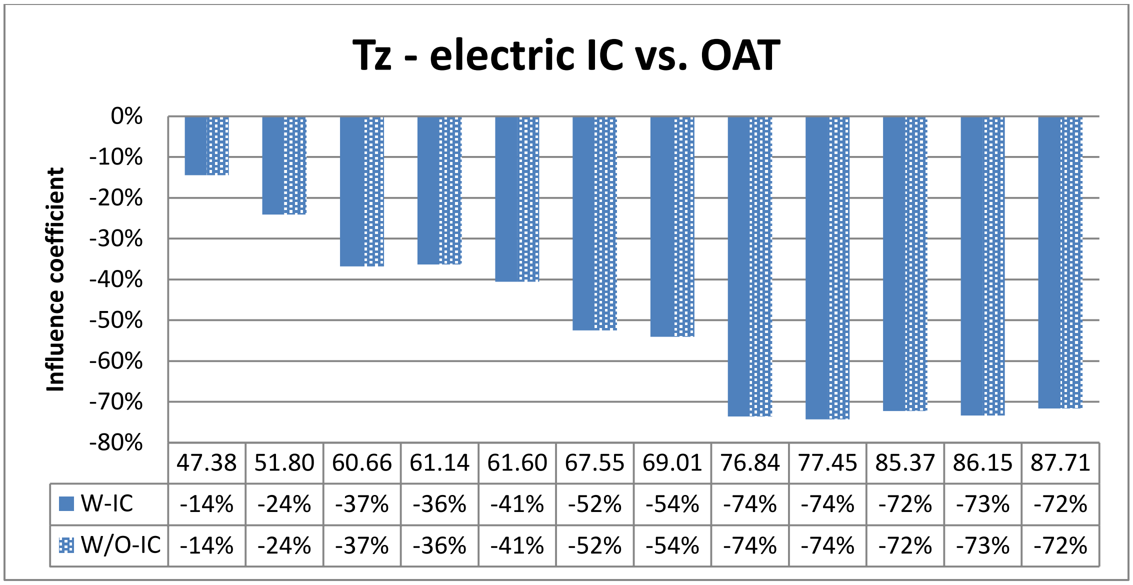



**Figure 4-29** Electric consumption IC value for the parameter Tz

Figure 4-29 implies that the zone temperature setpoint parameter has the same sensitivity for both the SDVAV system with the economizer and system without the economizer. Additionally, the zone temperature setpoint parameter is more sensitive to electric consumption in hot OATs.

4.6.2 Chilled water

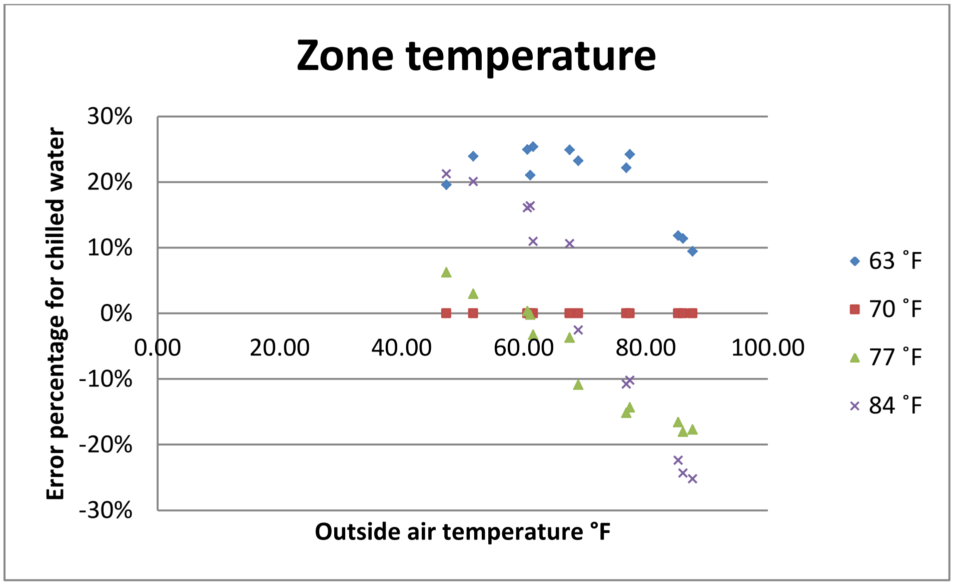



**Figure 4-30** Chilled water consumption for the parameter Tz, SDVAV with the economizer

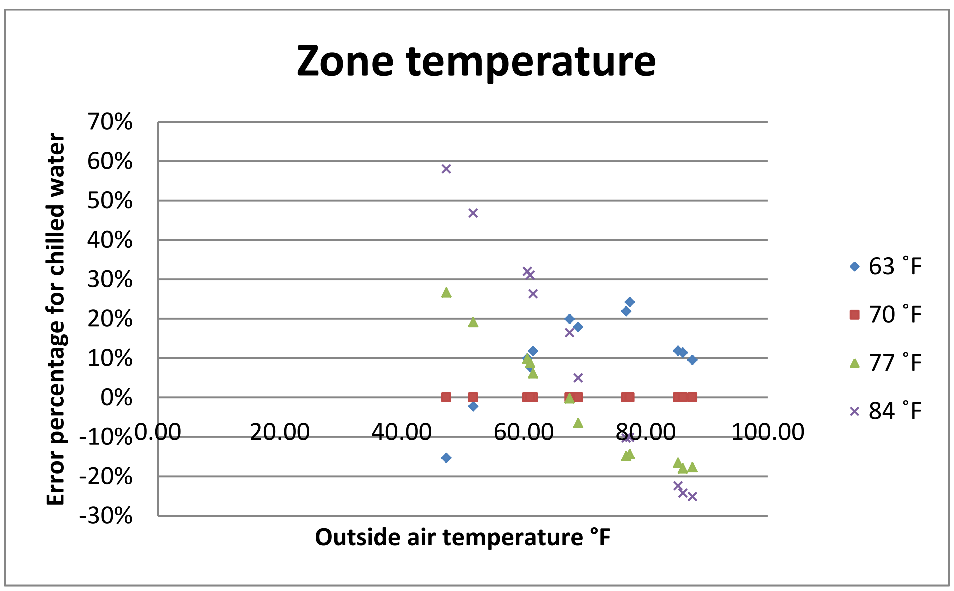



**Figure 4-31** Chilled water consumption for the parameter Tz, SDVAV without the economizer

Figure 4-30 and Figure 4-31 are the chilled water consumption difference percentage data for the system with the economizer and the system without the economizer. For the system with the economizer, the chilled water consumption will increase when decreasing the zone temperature in cold weather, while the chilled water consumption for the system without the economizer will decrease in the cold weather. For both systems, the chilled water consumption will decrease when the average monthly OAT is higher than 61.6˚F. This phenomenon can be explained using Equation 4-1. The $\Delta T$ for the system with the economizer will not be impacted as much as for the system without the economizer. In the system with the economizer, the outside air temperature can be used for balancing this extra heat gain from the zone.

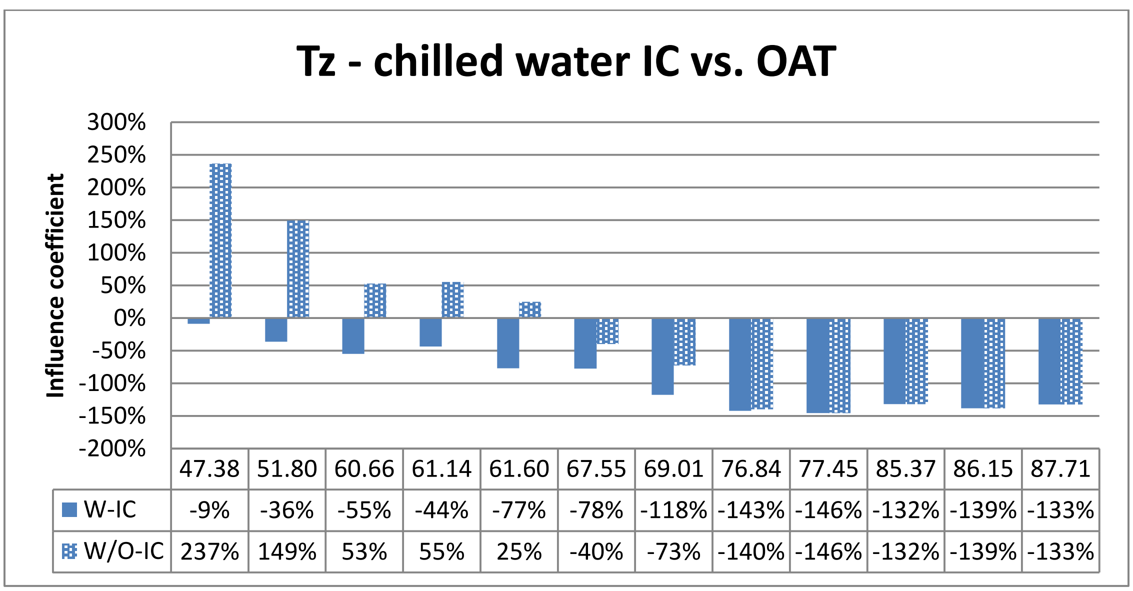


**Figure 4-32** Chilled water consumption IC value for the parameter Tz

Figure 4-32 shows the chilled water influence coefficient caused by the zone temperature. The chilled water consumption for the system without the economizer is more sensitive than the system with the economizer in cold OATs. In the hot OATs the sensitivity for both systems is almost the same.

4.6.3 Hot water

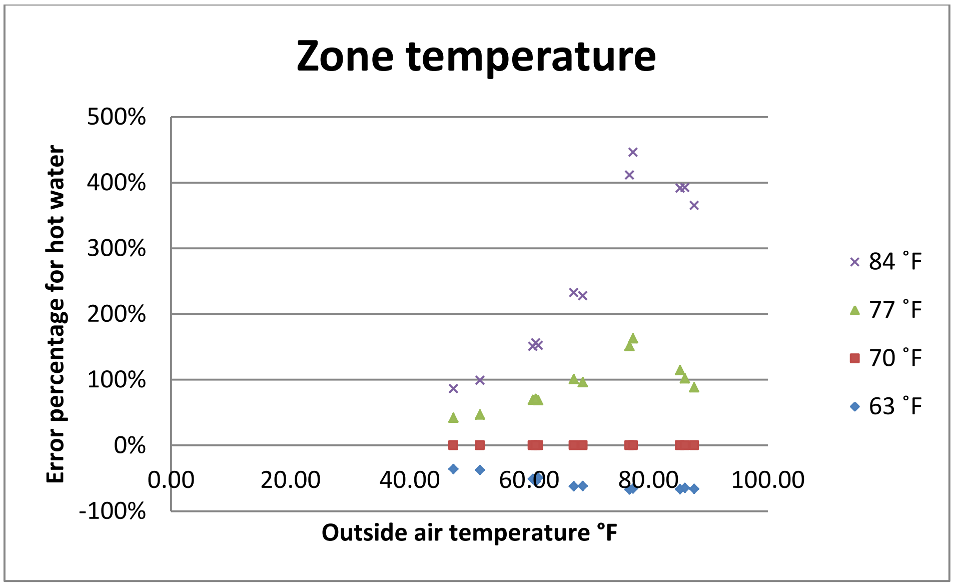



**Figure 4-33** Hot water consumption for the parameter Tz, SDVAV with the economizer

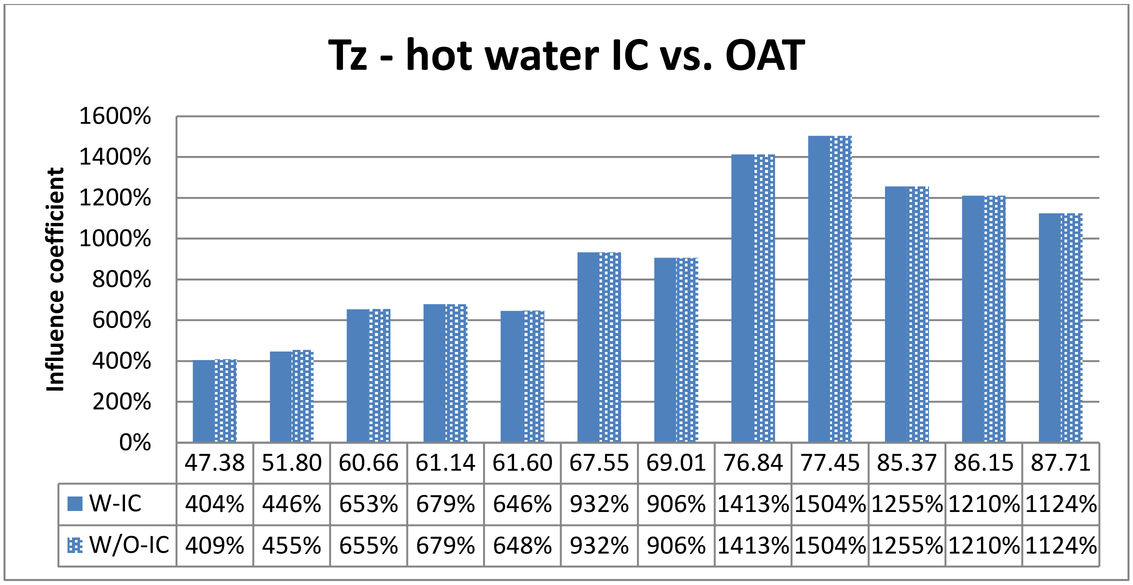



**Figure 4-34** Hot water consumption IC value for the parameter Tz

Figure 4-33 shows that when the zone temperature increases, the hot water consumption will increase simultaneously. This is because when increasing the zone temperature setpoint, more hot water is expected to be consumed to meet the setpoint. Figure 4-34 shows that the influence coefficient value has been reduced for temperatures over 77.45˚F. When the monthly average OAT is higher than 77.45˚F, the zone absorbs the heat from the outside air for most of the time in that month, so the hot water consumption will be decreased.

## 4.7 Cooling coil temperature (Tc)

4.7.1 Electric

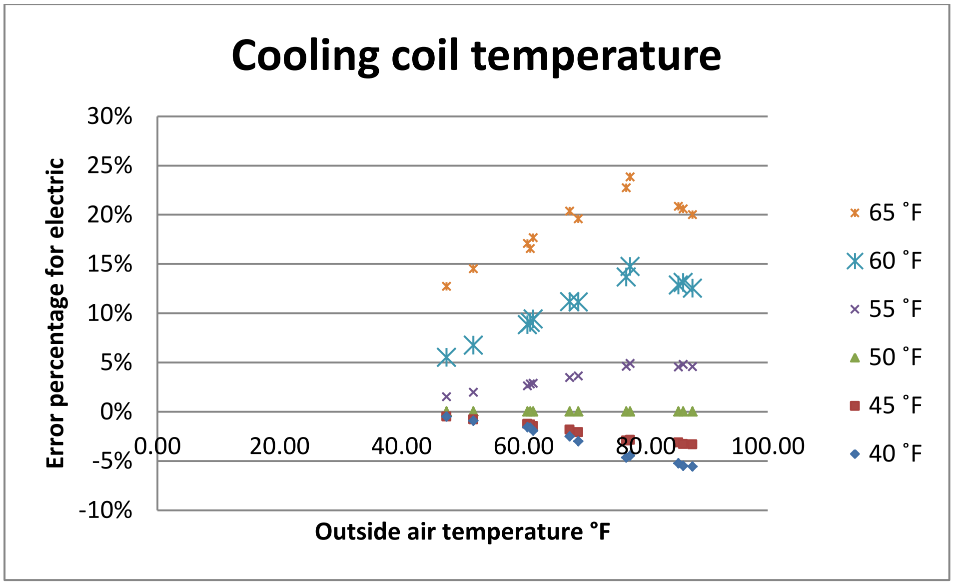



**Figure 4-35** Electric consumption for the parameter Tc, SDVAV with the economizer

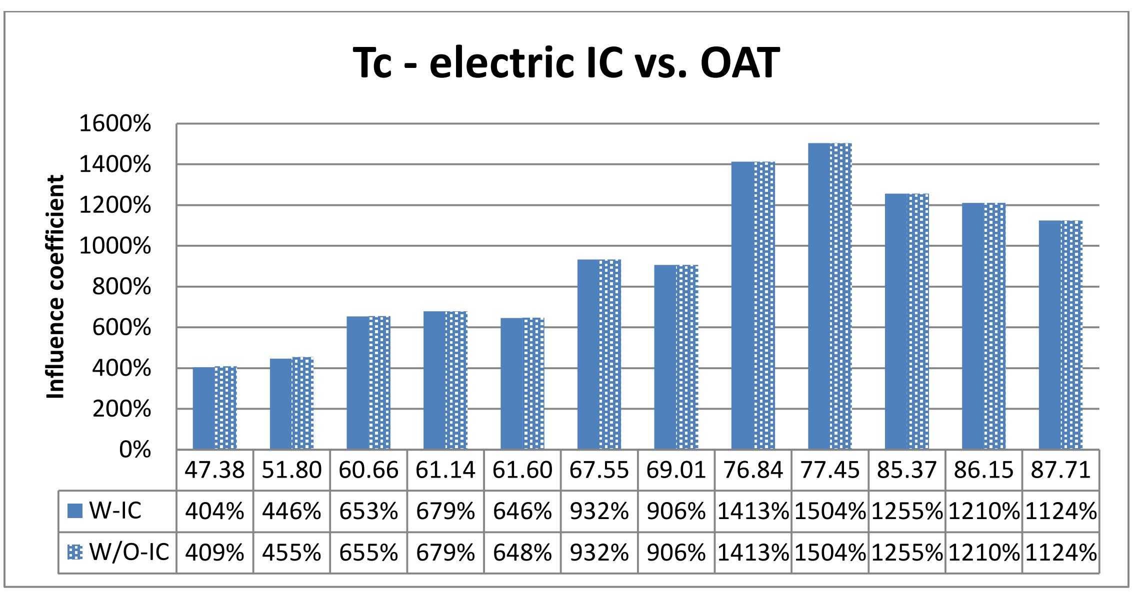



**Figure 4-36** Electric consumption IC value for the parameter Tc

Figure 4-35 shows that when increasing the cooling coil temperature, the electric consumption will increase. This is because the fan needs to work harder to blow more air through the coil to balance the cooling load in the zone (Equation 4-1). When the fan works at its maximum load under a certain temperature, the variable-frequency drive fan will work as the constant speed fan. That is why even though the outside air temperature gets warmer, the sensitivity caused by the cooling coil temperature to electric consumption is reduced, as shown in Figure 4-36. Figure 4-36 shows that the electric consumption influence coefficients, which are caused by adjusting the cooling coil temperature, are the same for both the system with the economizer and the system without the economizer.

4.7.2 Chilled water

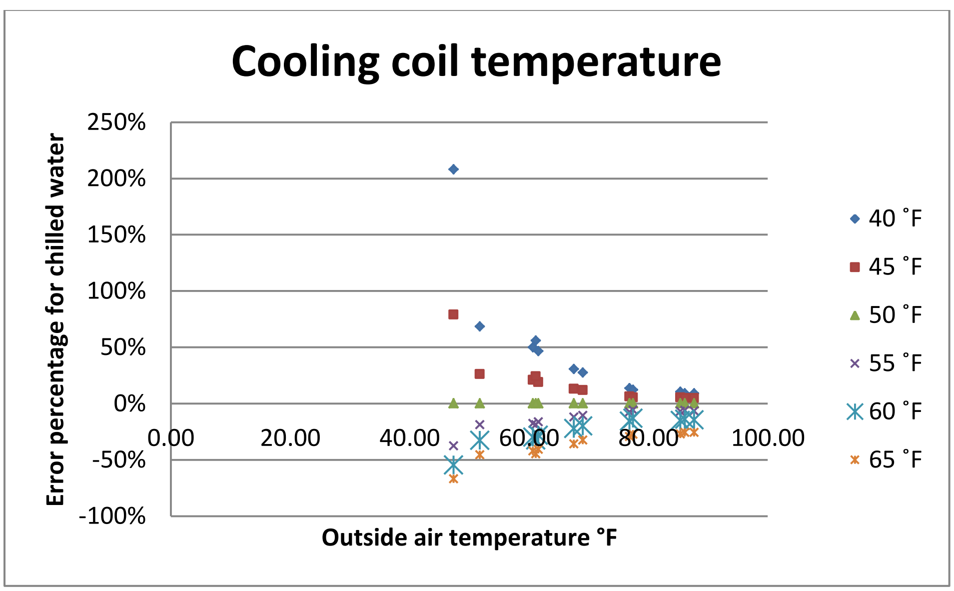



**Figure 4-37** Chilled water consumption for the parameter Tc, SDVAV with the economizer

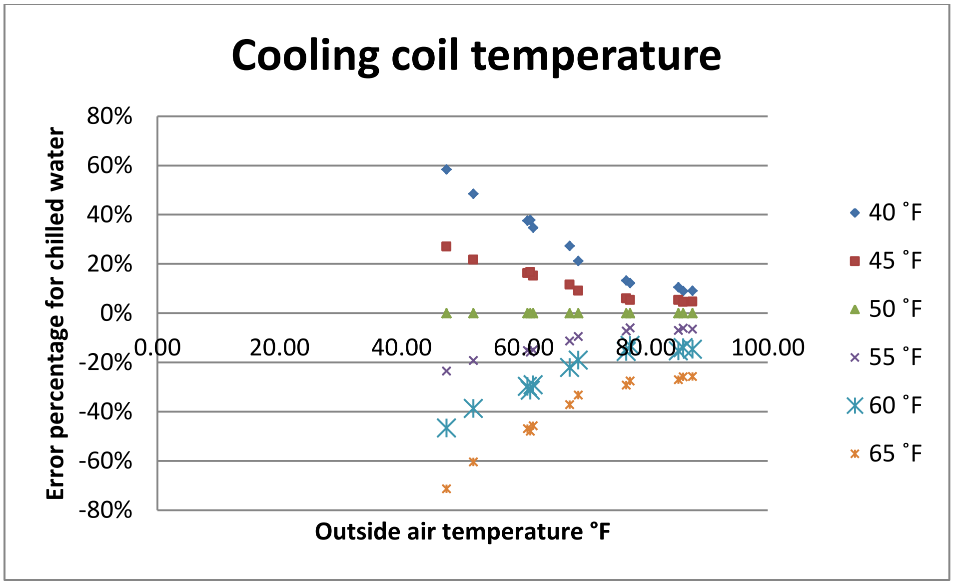
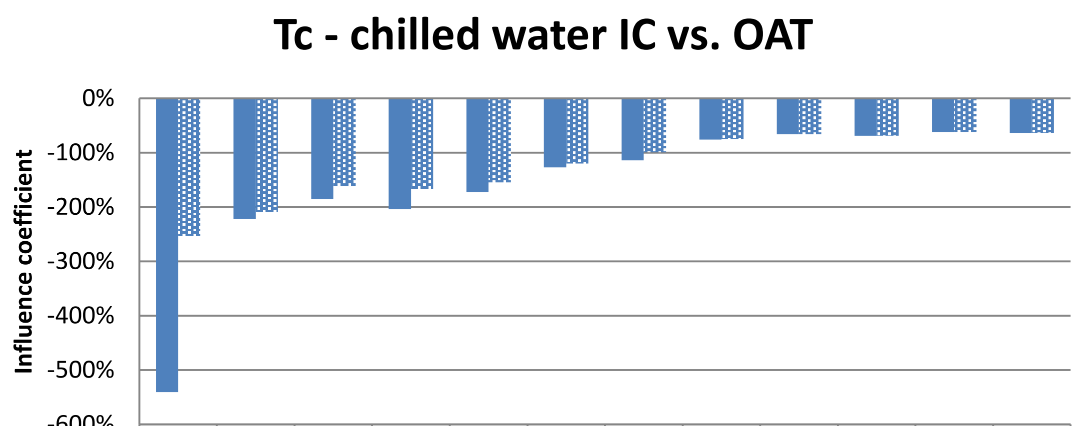



**Figure 4-38** Chilled water consumption for the parameter Tc, SDVAV without the economizer

Figure 4-37 and Figure 4-38 show the chilled water consumption for the SDVAV system with the economizer and the system without the economizer, respectively. The patterns of the chilled water consumption for these two systems are similar to each other. The chilled water consumption is increased by reducing the cooling coil temperature. This can be explained by Equation 4-1. The $\Delta T$ will be increased when reducing cooling coil temperature, so if the reduction in flow rate is not significant, the cooling load on the cooling coil will be increased.

As shown in Figure 4-39, the sensitivity caused by cooling coil temperature adjustments to the chilled water consumption are also similar for these systems, except for a monthly average outside air temperature below 47 ˚F. The chilled water consumption for the system with the economizer is more sensitive than the system without the economizer in cold OATs.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | -541% | -222% | -185% | -204% | -173% | -127% | -114% | -76% | -66% | -69% | -62% | -63% |
| W/O-IC | -254% | -209% | -161% | -166% | -155% | -120% | -99% | -75% | -66% | -69% | -62% | -63% |

**Figure 4-39** Chilled water consumption IC value for the parameter Tc

4.7.3 Hot water

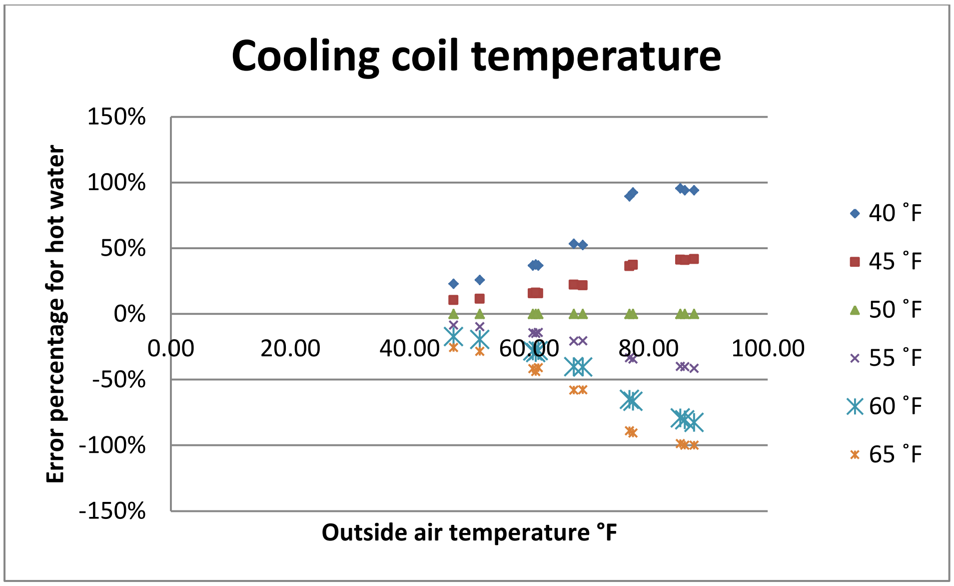



**Figure 4-40** Hot water consumption for the parameter Tc, SDVAV with the economizer

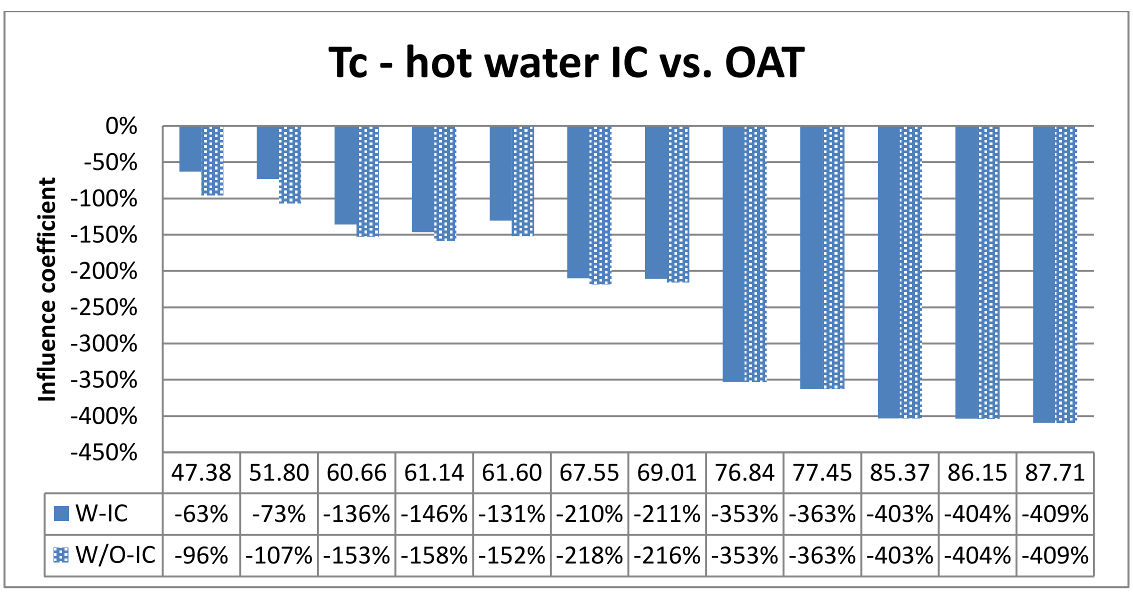



**Figure 4-41** Hot water consumption IC value for the parameter Tc

Figure 4-40 shows the hot water consumption results for the systems with the economizer and without the economizer. When the outside air temperature is between the economizer enabled ranges of 30˚F to 60˚F, the results for these two systems are different from each other, otherwise they are the same, see Figure 4-41. The reason for this is that free cooling in the economizer can adjust the mixed temperature to the best fit for the zone temperature by adjusting the cooling coil temperature. That makes the hot water consumption less sensitive than in the system without the economizer.

### 4.8 Average lighting energy consumption (Lighting)

4.8.1 Electric

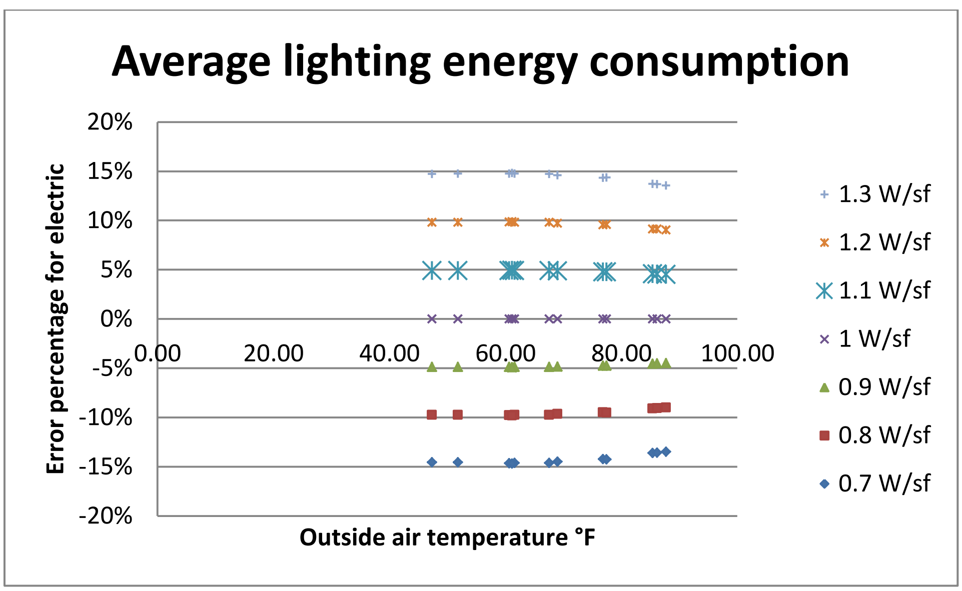



**Figure 4-42** Electric consumption for the parameter lighting, SDVAV with the economizer

Figure 4-42 shows that the electric consumption is decreased by decreasing the lighting power. This can be explained by Equation 4-1. When the zone cooling load decreases, the coil cooling load $Q_{cooling\ coil}$ is reduced, the temperature difference between mixed air and supply air does not change, and airflow $\dot{V}$ is reduced for keeping the zone temperature at its setpoint. From Equation 4-2 through Equation 4-4, less airflow leads to lower fan power. The physical explanation is the same as the relationship between the plug load parameter and the nighttime lighting and plug load ratio.

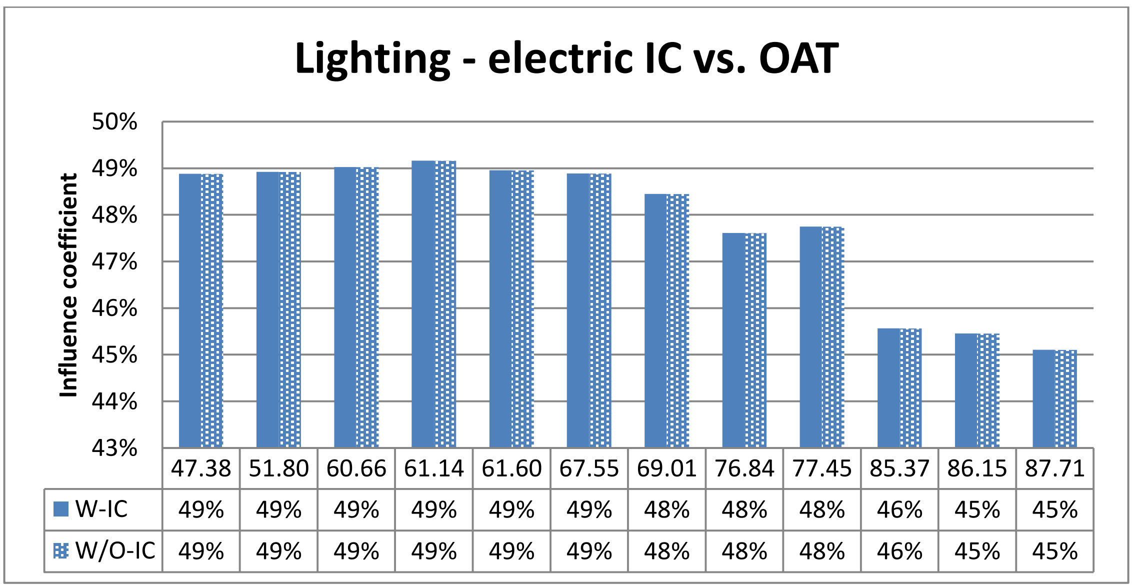



**Figure 4-43** Electric consumption IC value for the parameter lighting

Figure 4-43 shows that the sensitivity of electric consumption caused by the lighting parameter is the same for both the systems with the economizer and without the economizer.

4.8.2 Chilled water

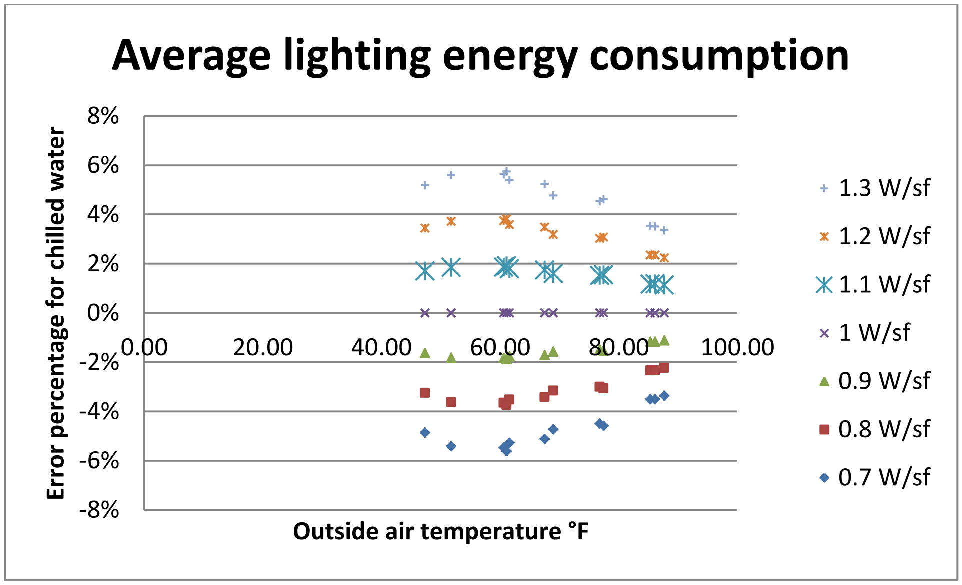
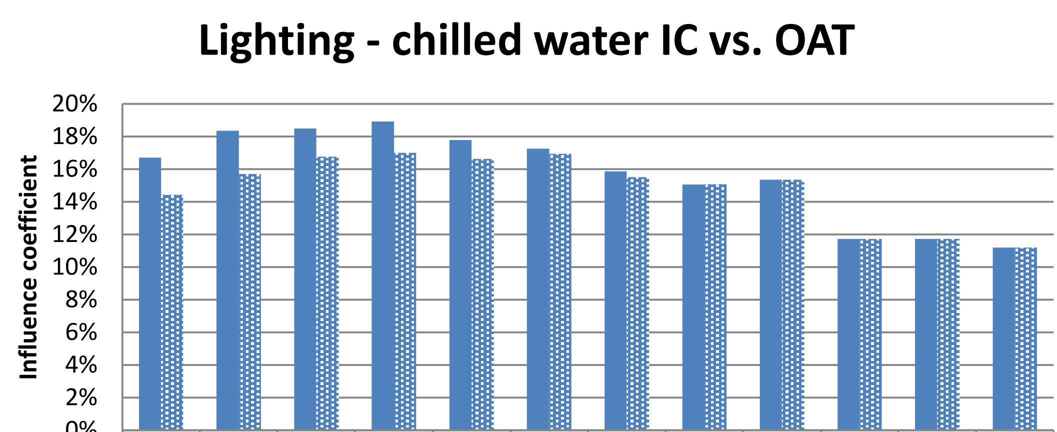



**Figure 4-44** Chilled water consumption for the parameter lighting, SDVAV with the economizer

The pattern of the results for chilled water consumption is the same for both SDVAV systems with and without the economizer. When the lighting power has been reduced, the chilled water consumption will be reduced, see Figure 4-44. The reason for this is that the cooling load in the zone will be reduced, so the requirement for chilled water will be reduced.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 17% | 18% | 18% | 19% | 18% | 17% | 16% | 15% | 15% | 12% | 12% | 11% |
| W/O-IC | 14% | 16% | 17% | 17% | 17% | 17% | 16% | 15% | 15% | 12% | 12% | 11% |

**Figure 4-45** Chilled water consumption IC value for the parameter lighting

Figure 4-45 shows that the system with the economizer is more sensitive in cold OATs. The reason is similar to the window-wall ratio parameter effect for chilled water.

4.8.3 Hot water

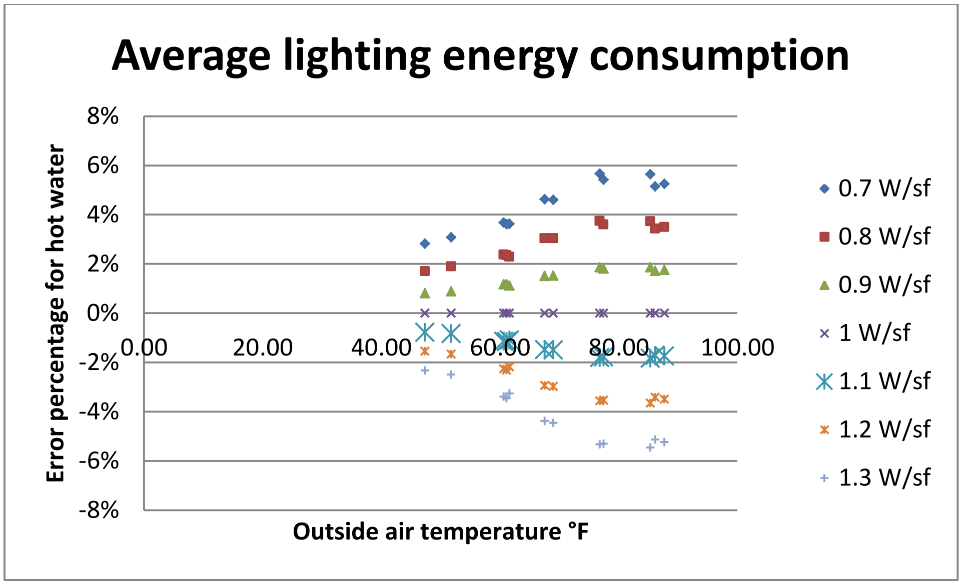



**Figure 4-46** Hot water consumption for the parameter Tz, SDVAV with the economizer

Figure 4-46 shows that hot water consumption will be increased when the lighting power is decreased.  Lighting is the main electric equipment for offering heat gain.

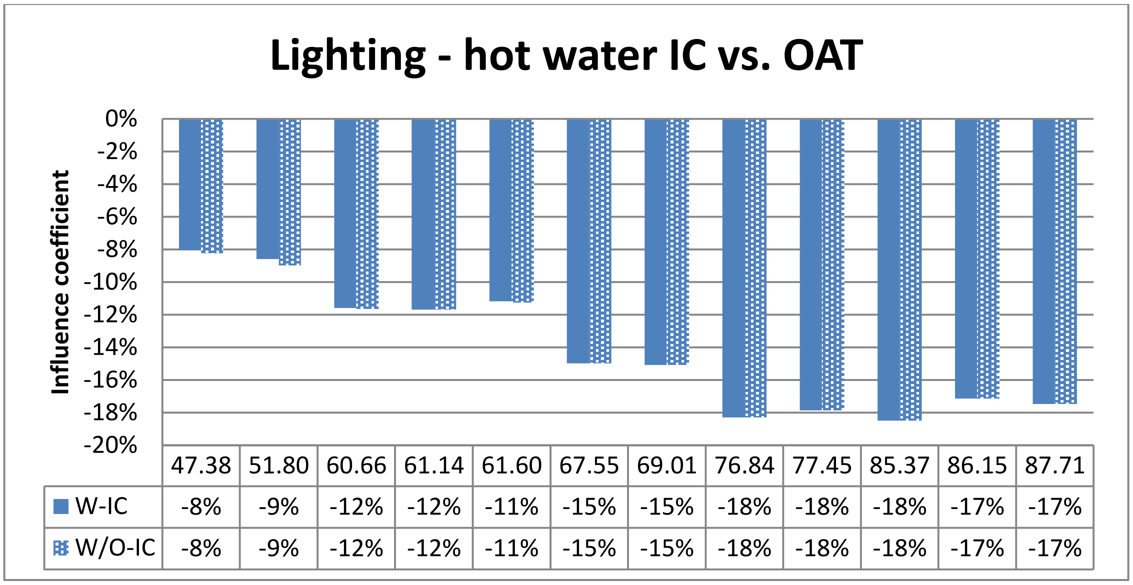



**Figure 4-47** Hot water consumption IC value for the parameter lighting

Figure 4-47 shows that the hot water consumption caused by adjusting the lighting parameter is more sensitive in warm OATs. This is because in warm weather the hot water consumption is less than that in cold weather. Assume the total hot water consumption is the denominator. The change in the hot water consumption caused by adjusting the lighting parameter is the numerator. A small change in the numerator will cause a bigger change if the denominator is smaller.

### 4.9 VAV fan power (FP)

Fan power in WinAM 4.3 is described in HP/kCFM. A lower value means less power will be used for the flow rate at a thousand cubic feet per minute. In other words, the lower the value, the more energy efficient the fan will be.

4.9.1 Electric

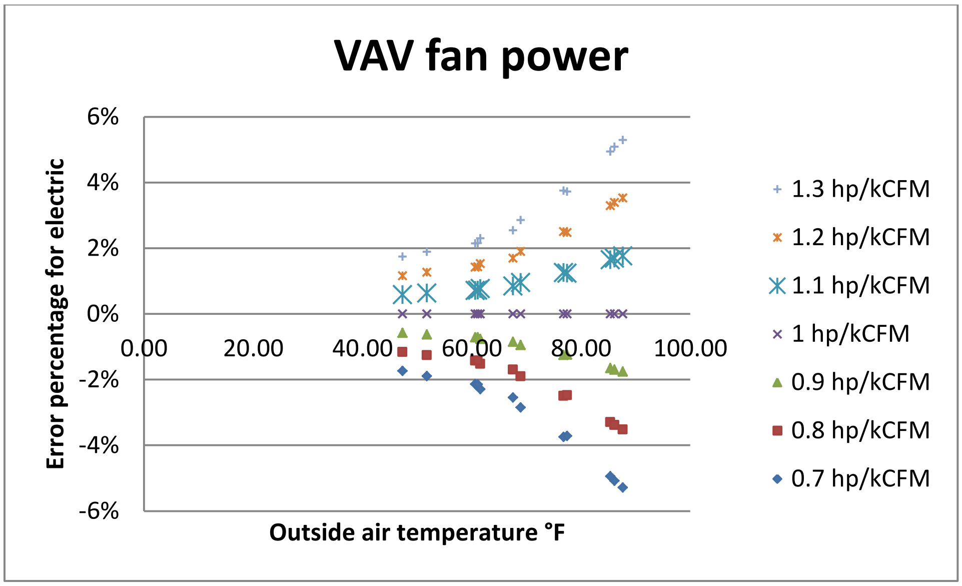
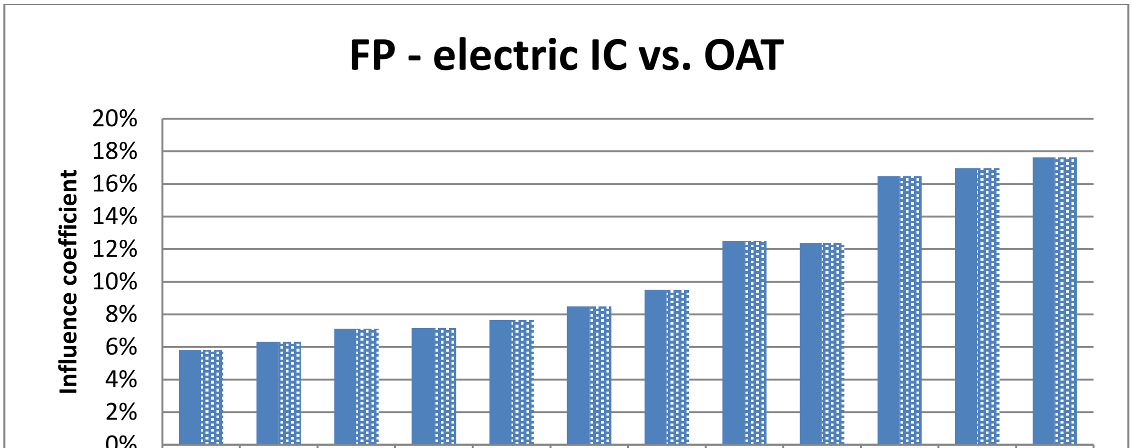



**Figure 4-48** Electric consumption for the parameter FP, SDVAV with the economizer

Figure 4-48 shows that when the fan power has been adjusted from 1.3 HP/kCFM to 0.7 HP/kCFM, the electric consumption will be reduced.  This is because the fan is more efficient, so less energy will be used to create the same amount of airflow.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 6% | 6% | 7% | 7% | 8% | 8% | 10% | 12% | 12% | 16% | 17% | 18% |
| W/O-IC | 6% | 6% | 7% | 7% | 8% | 8% | 10% | 12% | 12% | 16% | 17% | 18% |

**Figure 4-49** Electric consumption IC value for the parameter FP

Figure 4-49 shows that the fan power parameter is more sensitive in warm OATs than in cold OATs.

4.9.2 Chilled water

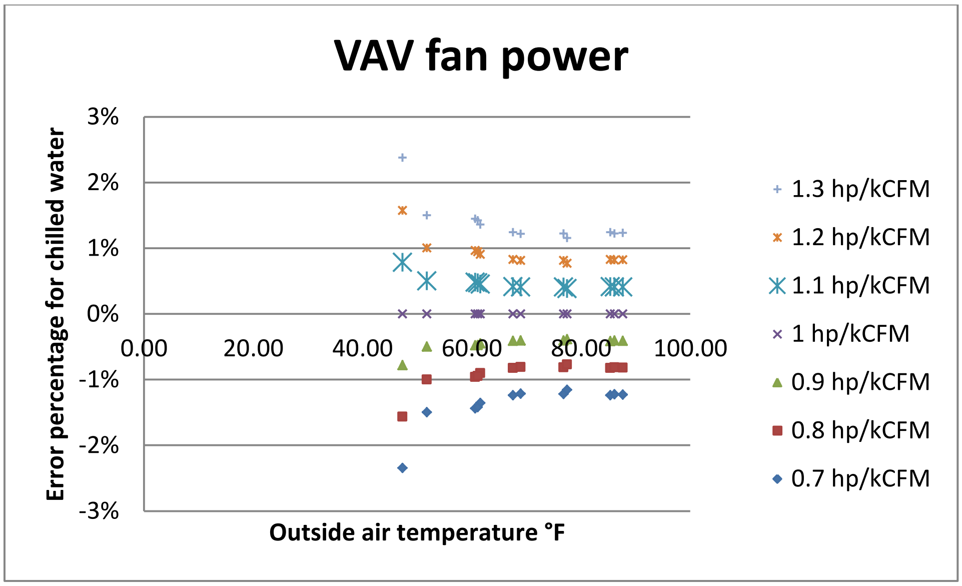



**Figure 4-50** Chilled water consumption for the parameter FP, SDVAV with the economizer

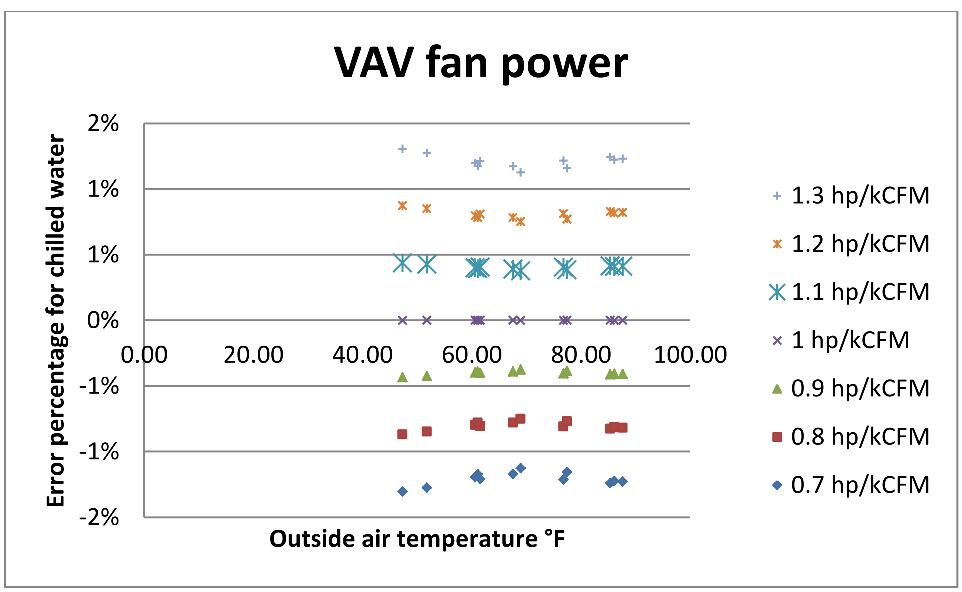



**Figure 4-51** Chilled water consumption for the parameter FP, SDVAV without the economizer

Figure 4-50 and Figure 4-51 are the chilled water consumption for the system with the economizer and the system without the economizer. The pattern of the results for the chilled water consumption for both systems is similar. The smaller the number in the legend, the higher the efficiency of the fan. When the fan power increases, the chilled water consumption decreases simultaneously. This can be explained by the fact that the temperature across the fan changes when adjusting the fan power.

Figure 4-52 shows that the difference exists when average monthly OAT falls below 76.84°F. When fan power changes, the temperature across the fan will also be simultaneously changed. For the system with the economizer, free cooling will be used.

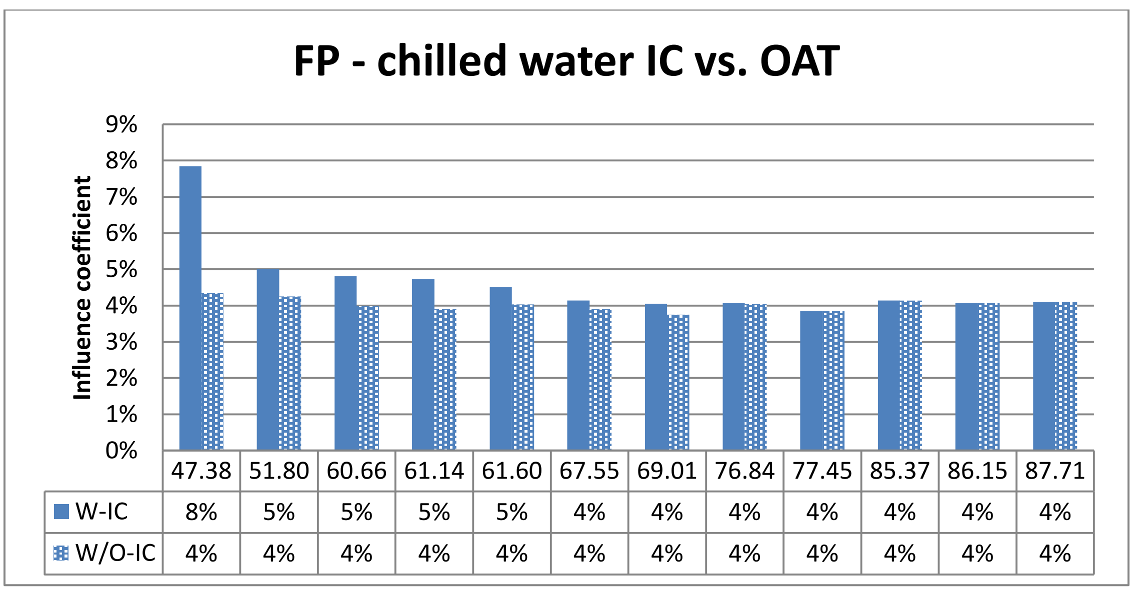


**Figure 4-52** Chilled water consumption IC value for the parameter FP

4.9.3 Hot water

The fan power parameter does not impact the hot water consumption.

**4.10 Nighttime lighting and plug load ratio (NLPL)**

This parameter is used for deciding the lighting and plug load ratio at night. The impact caused by this parameter is similar to the impact caused by the lighting power.

4.10.1 Electric

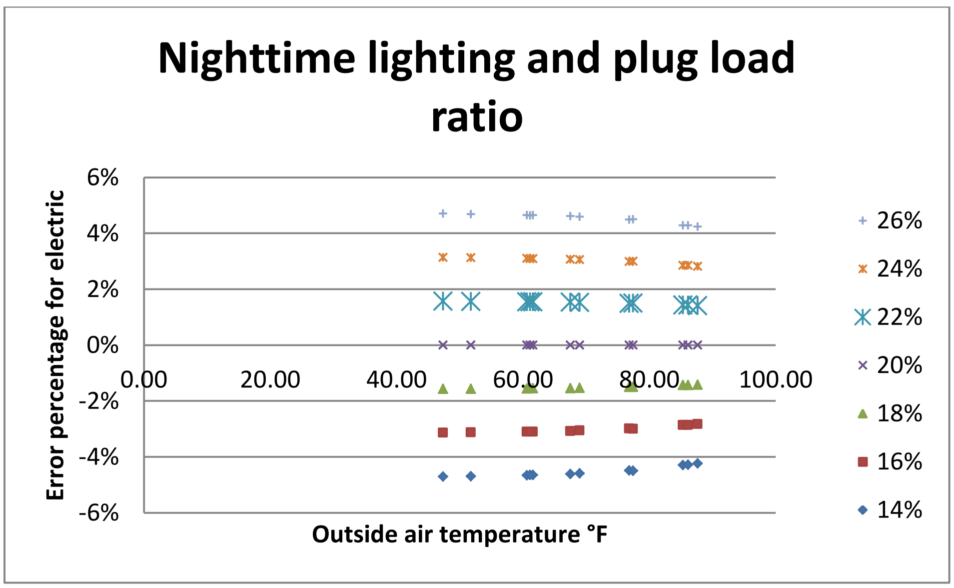



**Figure 4-53** Electric consumption for the parameter NLPL, SDVAV with the economizer

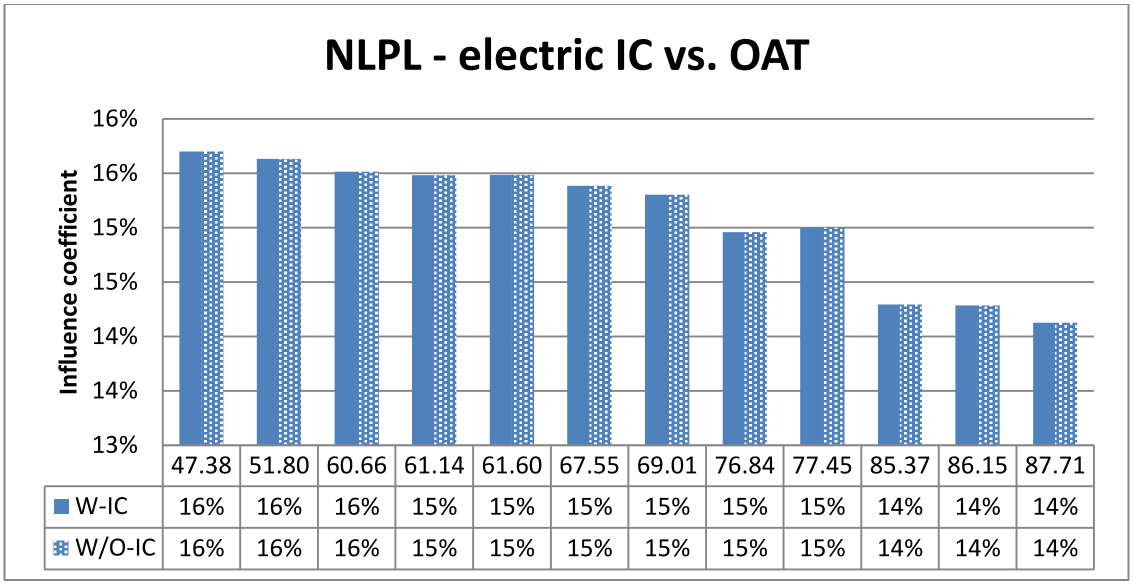



**Figure 4-54** Electric consumption IC value for the parameter NLPL

Figure 4-53 shows that the electric consumption is decreased by decreasing the NLPL power. The physical explanation is the same as that of the plug load parameter. Figure 4-54 implies that the electric influence coefficients caused by adjusting the NLPL parameter are the same for both the system with the economizer and the system without the economizer. The physical explanation of the impact to the electric consumption caused by the NLPL is the same as the physical explanation of the lighting parameter. The cooling load in the zone will be decreased when reducing the interior zone cooling load. If the temperature difference between the mixed air and the supply air is not changed, the supply airflow rate will be reduced. This means that the fan can work less.

4.10.2 Chilled water

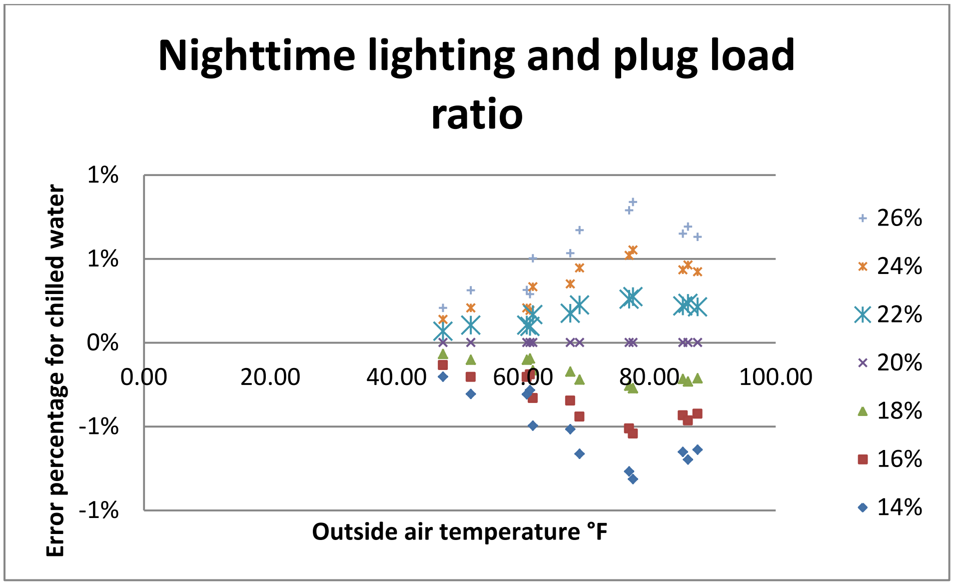
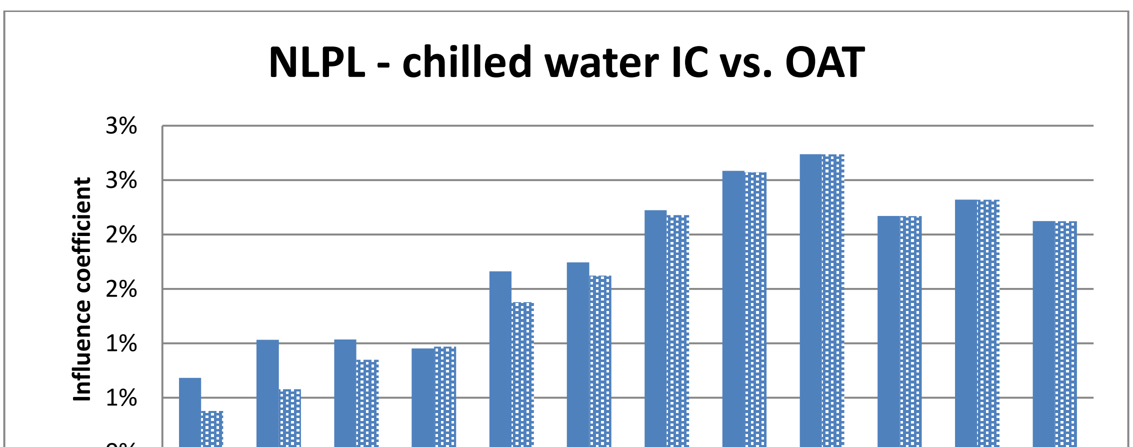



**Figure 4-55** Chilled water consumption for the parameter NLPL, SDVAV with the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 1% | 1% | 1% | 1% | 2% | 2% | 2% | 3% | 3% | 2% | 2% | 2% |
| W/O-IC | 0% | 1% | 1% | 1% | 1% | 2% | 2% | 3% | 3% | 2% | 2% | 2% |

**Figure 4-56** Chilled water consumption IC value for the parameter NLPL

The chilled water consumption results impacted by adjusting the NLPL parameter can be observed in Figure 4-55. When reduce the NLPL parameter, the chilled water consumption will reduced. From Equation 4-1, reducing the NLPL parameter the heating load in the zone will be reduced, so the cooling load required in cooling coil will be reduced. That is why when reducing the NLPL parameter, the chilled water consumption will be reduced. The chilled water consumption is more sensitive in the cold OATs for the system with the economizer, see Figure 4-56. The economizer will make the system use less water in the temperature range of 30°F to 60°F.

### 4.10.3 Hot water

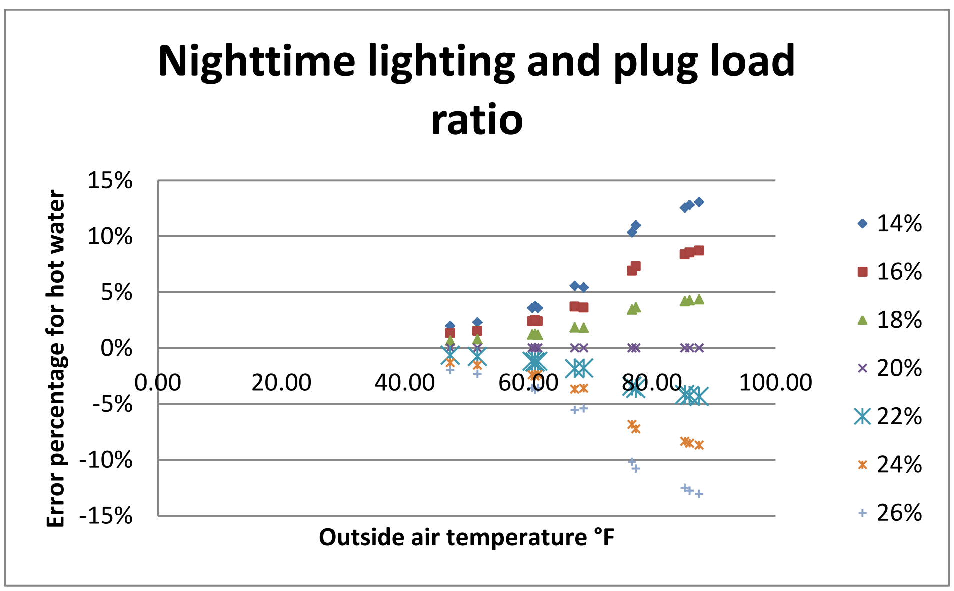



**Figure 4-57** Hot water consumption for the parameter NLPL, SDVAV with the economizer

Figure 4-57 shows when there is an increase in the NLPL parameter, the hot water consumption will be decreased.  This is because increasing the NLPL parameter will increase the interior heat gain.

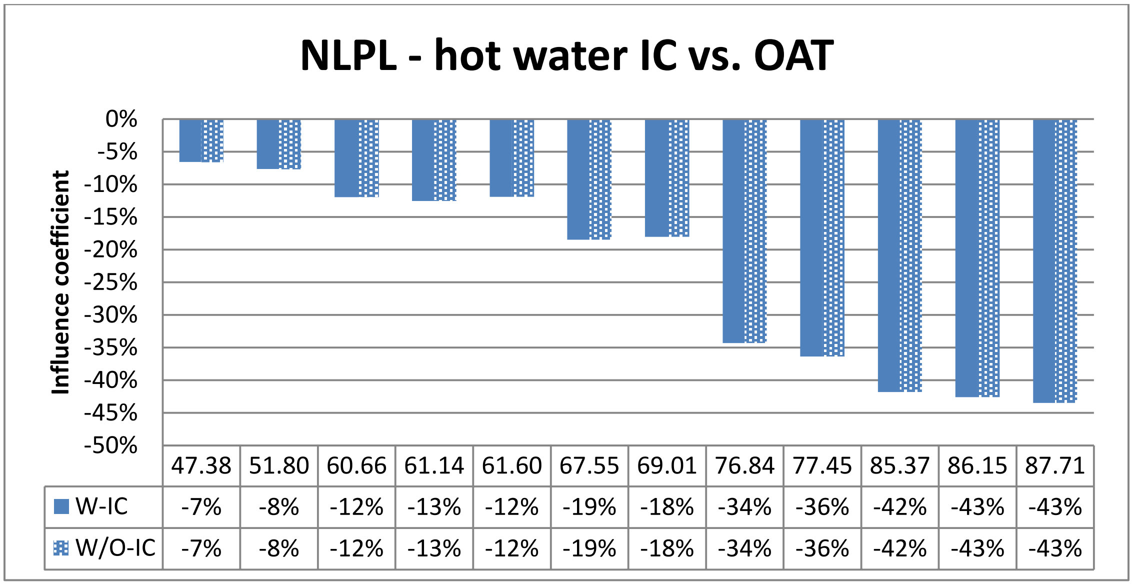


**Figure 4-58** Hot water consumption IC value for the parameter NLPL

Figure 4-58 shows that the hot water consumption influence coefficient values are impacted more by adjustment to the NLPL parameter than adjustment to the lighting parameter.  This is because hot water will be consumed more in the nighttime compared with the daytime.

### 4.11 Wall R-value (Wall R)

The IC values for this parameter by adjusting $\pm$ 30% around the base model are all 0.

4.11.1 Electric

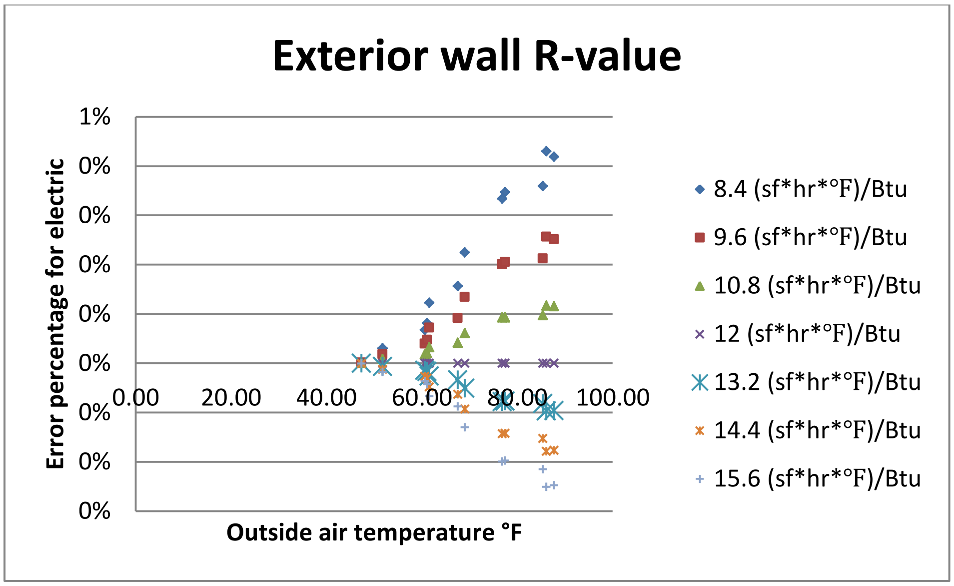



**Figure 4-59** Electric consumption for the parameter wall R, SDVAV with the economizer

Figure 4-59 shows that adjusting the R-value of the wall within $\pm$ 30% around the baseline does not have the obvious impact on the electric consumption.

4.11.2 Chilled water

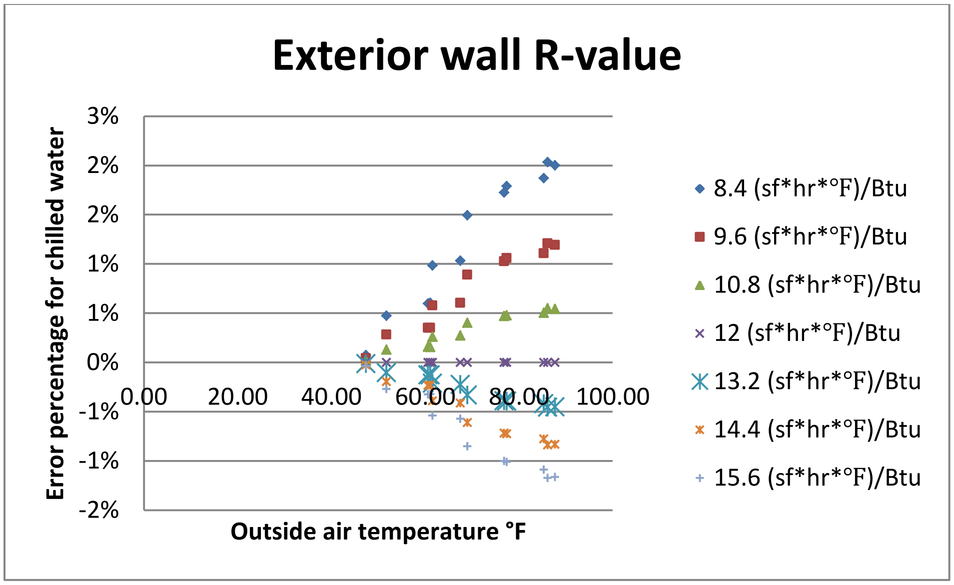



**Figure 4-60** Chilled water consumption for the parameter wall R, SDVAV with the economizer.

Figure 4-60 shows that when the R-value of the wall is decreased, chilled water consumption will be increased. This is because the lower the R-value, the less thermal resistance there will be. Equation 4-6 can be used to explain this phenomenon. When reducing the R-value, the heat transfer rate will be increased. This means that the lower the R-value, the quicker the heat flow will get through the wall. The physical explanation for this parameter is similar to the physical explanation of the window's U-value. The effects caused by this wall R-value parameter to the chilled water consumption are the same for the system with the economizer and the system without the economizer. R-value is the reciprocal of U-value.

4.11.3 Hot water

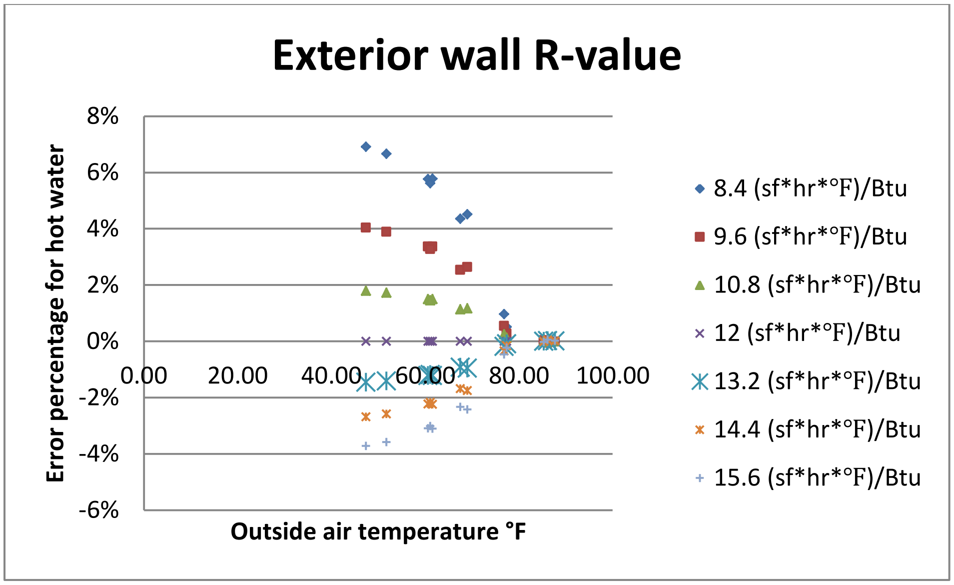



**Figure 4-61** Hot water consumption for the parameter wall R, SDVAV with the economizer

Figure 4-61 shows the hot water consumption results impacted by adjusting the R-value of the wall. As explained in the chilled water section for this parameter, lower R-value means higher heat transfer rate. Under this condition, more hot water is required to keep the room temperature at its setpoint.

## 4.12 Window U-value (Window U)

4.12.1 Electric

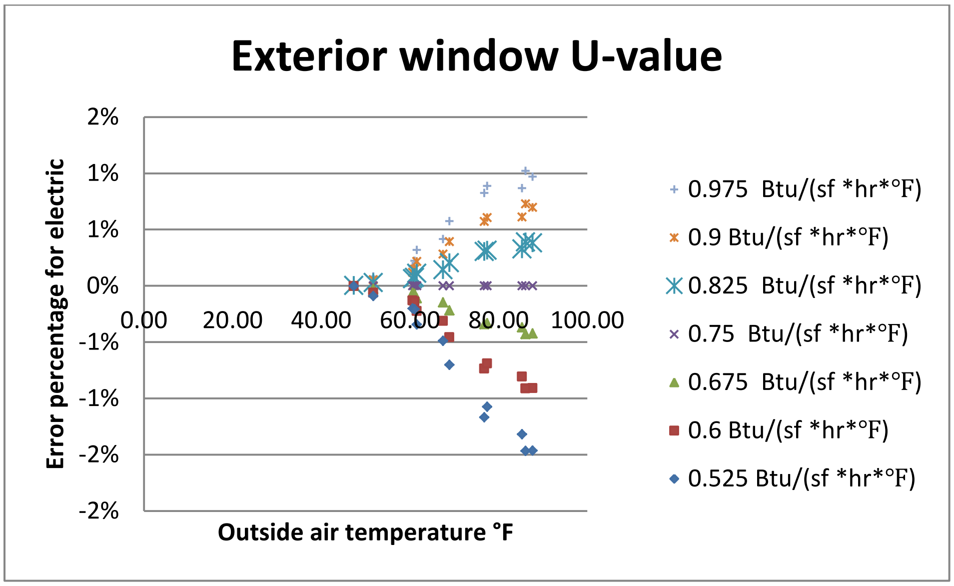



**Figure 4-62** Electric consumption for the parameter window U, SDVAV with the economizer

The effect to the system caused by the window U-value parameter is similar to the wall R-value effect, as shown in Figure 4-62. But the effect caused by adjusting the U-value within ± 30% is more compared with adjusting the R-value.

When increasing the U-value (decreasing the R-value) of the window, the electric consumption will be increased. Equation 4-6 explains that when increasing the U-value, the heat transfer rate will be increased. This means that the OAT will have more of an effect on the zone temperature when the zone has the higher U-value window compared to when the zone has the lower U-value window.

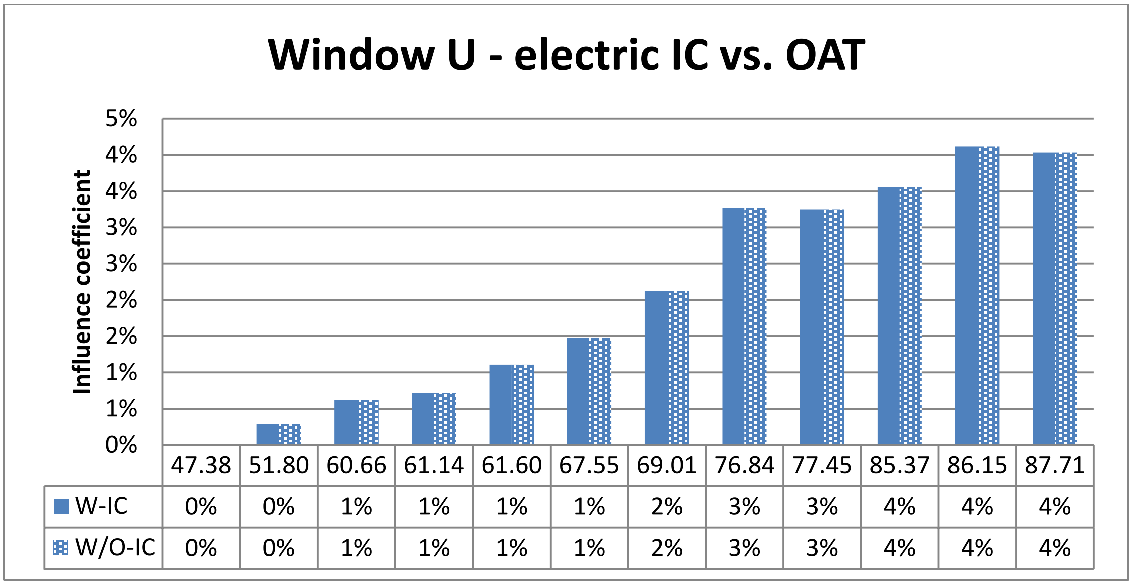


**Figure 4-63** Electric consumption IC value for the parameter window U

Figure 4-63 implies that the window U-value parameter is more sensitive in the hot OAT, and that the effect caused by this parameter is the same for both systems. From Equation 4-6, the temperature difference between the average monthly OAT and the zone temperature in the cold OATs can be as high as 27°F, and as high as 18°F in the hot OATs. This parameter is less sensitive to electric consumption in the cold OATs because the supply air temperature is 50°F. This is close to the coldest average OAT, but very far from the hottest average OAT.

4.12.2 Chilled water

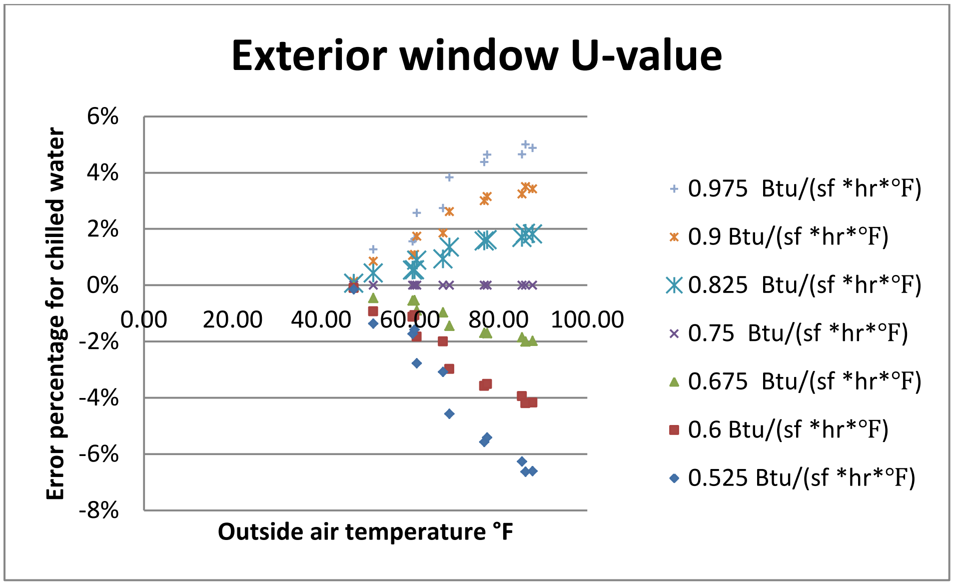



**Figure 4-64** Chilled water consumption for the parameter window U, SDVAV with the economizer

Figure 4-64 shows that chilled water consumption is impacted by adjusting the U-value of the window. This can be explained as similar to the input parameter's impact on electric.

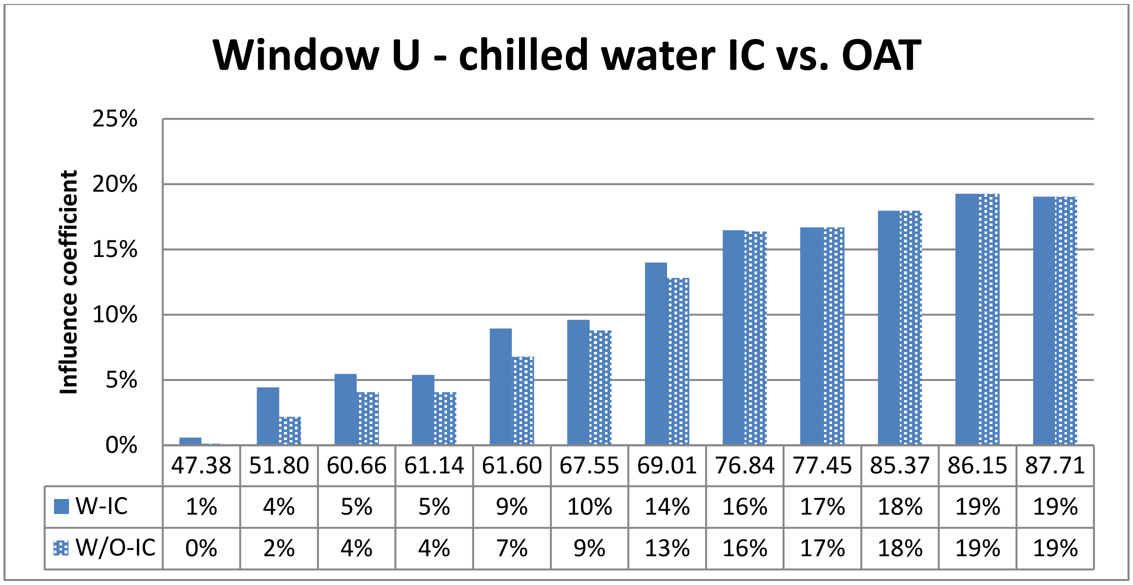



**Figure 4-65** Chilled water consumption IC value for the parameter window U

Figure 4-65 implies that chilled water consumption for the system with the economizer is more sensitive than the system without the economizer in cold OATs.

4.12.3 Hot water

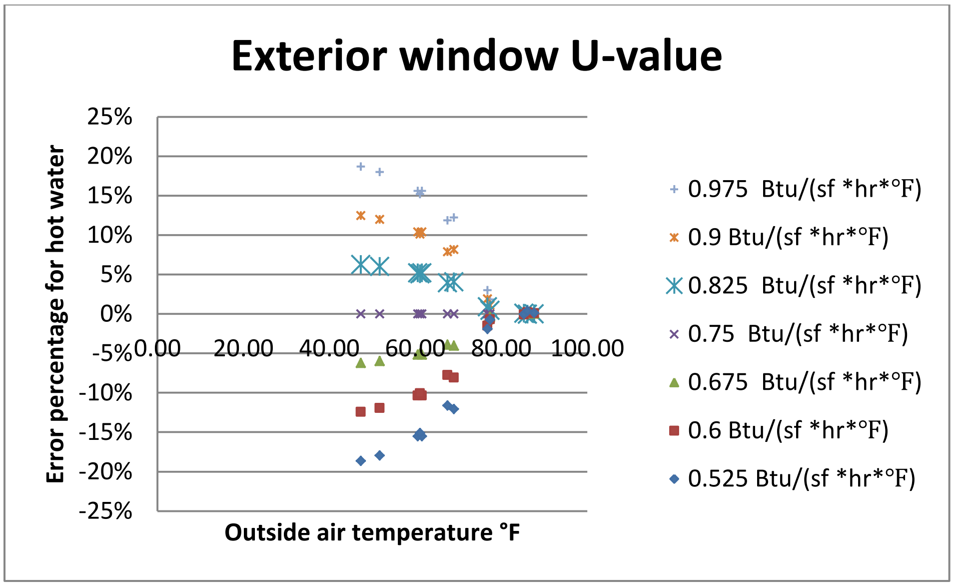
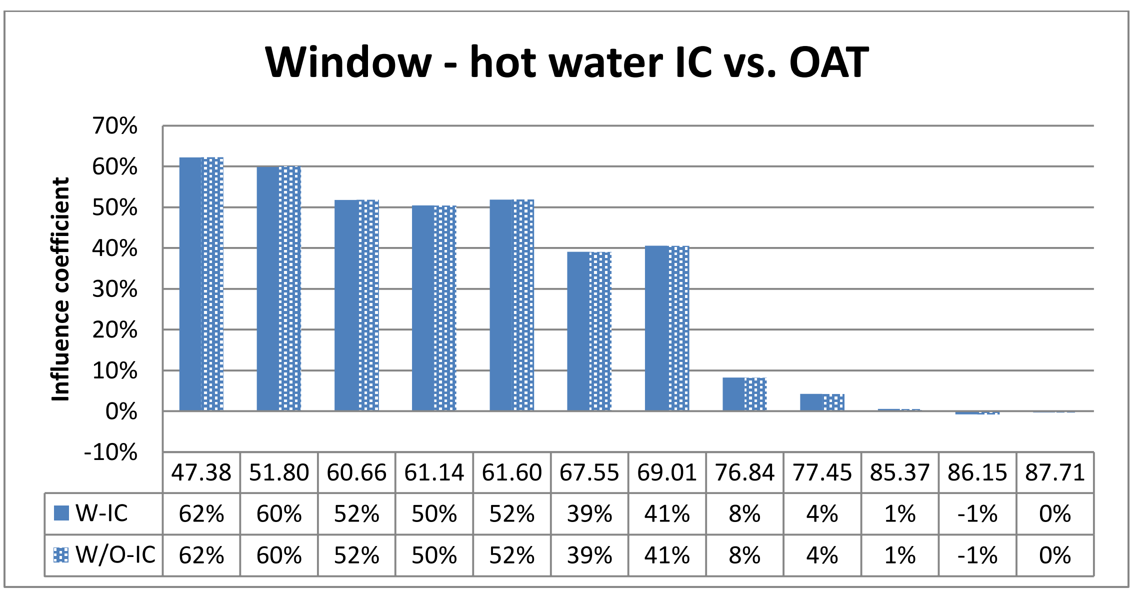



**Figure 4-66** Hot water consumption for the parameter window U, SDVAV with the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 62% | 60% | 52% | 50% | 52% | 39% | 41% | 8% | 4% | 1% | -1% | 0% |
| W/O-IC | 62% | 60% | 52% | 50% | 52% | 39% | 41% | 8% | 4% | 1% | -1% | 0% |

**Figure 4-67** Hot water consumption IC value for the parameter window U

Figure 4-66 shows the effect on hot water consumption by adjusting window U-value, is similar to the U-value effect of electric and chilled water consumption. When the window U-value is increased, the hot water consumption will be increased. The sensitivity level is the opposite compared to the electric consumption and the chilled water consumption, see Figure 4-67.

**4.13 Roof U-value (Roof U)**

4.13.1 Electric

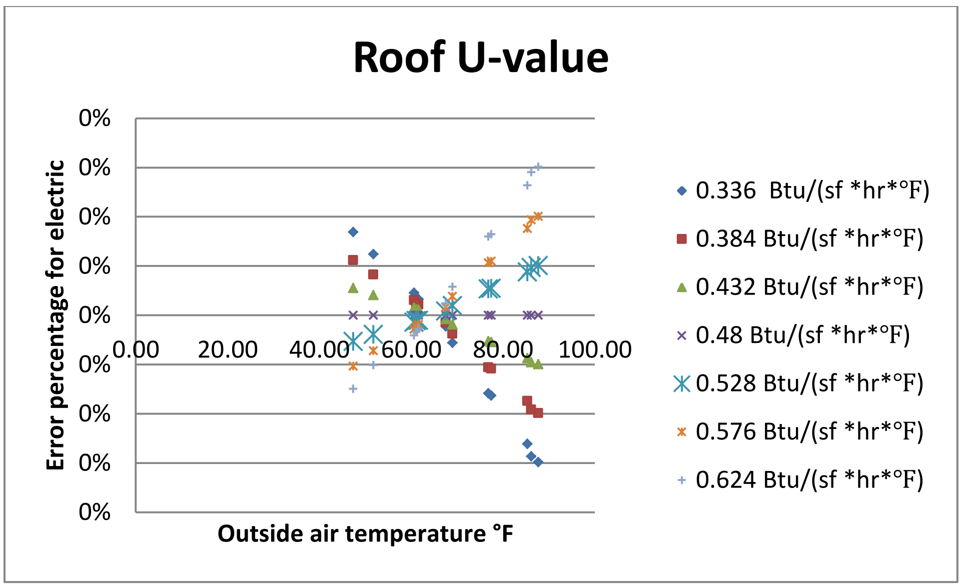



**Figure 4-68** Electric consumption for the parameter roof U, SDVAV with the economizer

The impact to the electric consumption by adjusting the U-value within ± 30% is under 1%. The system with the economizer and the system without the economizer have a similar pattern of results for electric consumption at each potential roof U-value, (Figure

4-69). Figure 4-68 is the general pattern of the results by adjusting the roof U-value which is different from the pattern of results by adjusting the window-wall ratio (Figure 4-11), wall R-value (Figure 4-59) and window U-value (Figure 4-62).

This difference is seen because the project has been divided into interior and exterior zones. The other parameters with U-values and R-values only connect with the exterior zone, but the roof U-value is relative to both the interior zone and the exterior zone. Equation 4-6 shows that the higher the R-value is the lower the heat transfer rates will be. A lower U-value indicates the less heat transfer rate through the components. If this occurs in hot OATs, the higher the R-value is the cooler the zone will be, and less electric energy will be consumed through the fan. In cold OATs, although the interior zone and the exterior zone can be kept at zone temperature setpoint, the interior zone needs to be cooled down. The heat transfer rate is low when the roof U-value is high. In this case, more electric energy will be consumed by the fan.

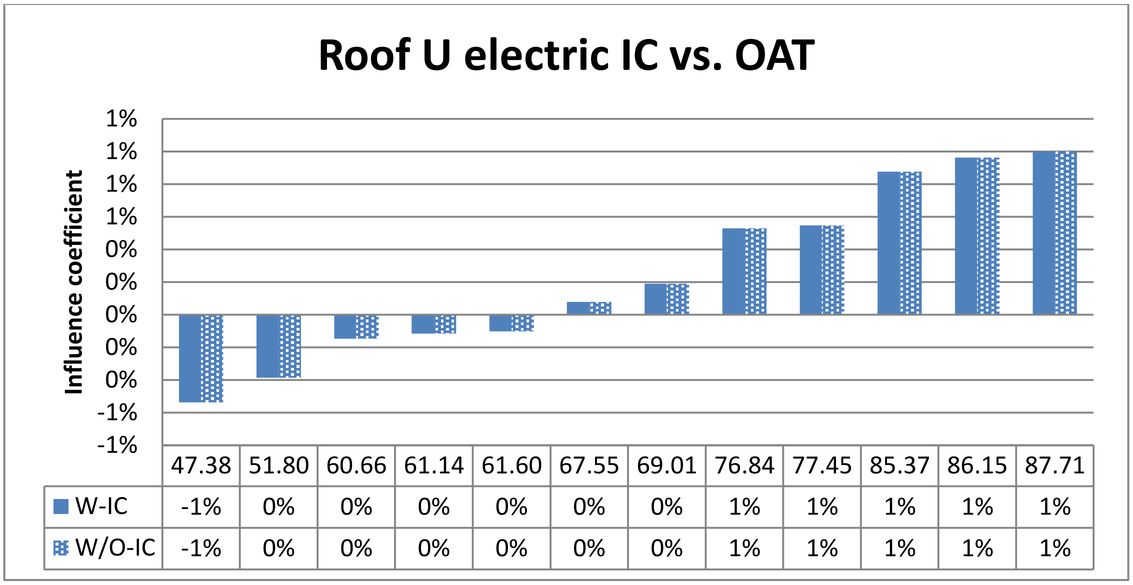


**Figure 4-69** Electric consumption IC value for the parameter roof U

Figure 4-69 implies that adjusting the roof R-value does not cause a difference in electric consumption between the system with the economizer and the system without the economizer.

4.13.2 Chilled water

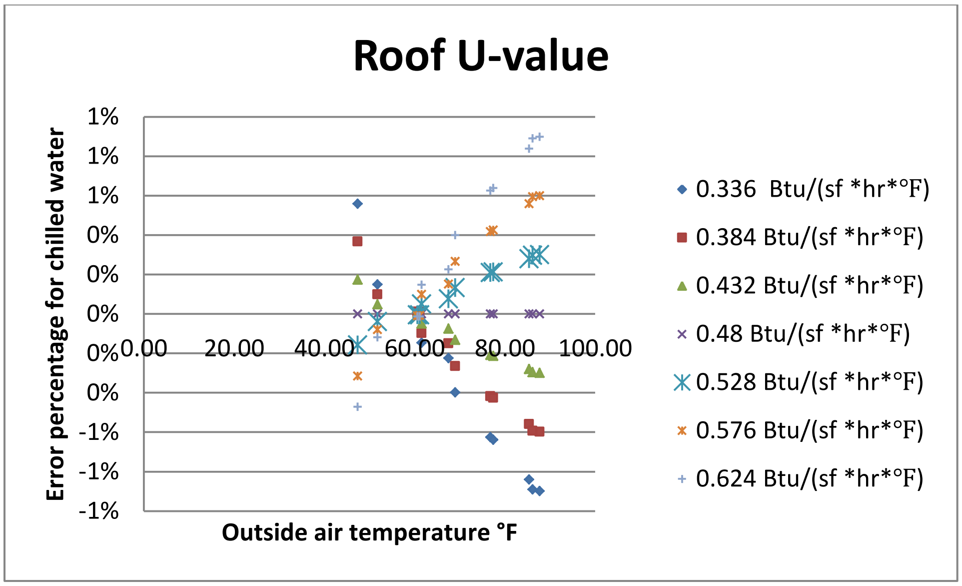



**Figure 4-70** Chilled water consumption for the parameter roof U, SDVAV with the economizer

Figure 4-70 shows the chilled water consumption results by roof U-value adjustment. The results pattern obtained by adjusting the roof U-value is different from the pattern of the results obtained by adjusting the window-wall ratio (Figure 4-13), the wall R-value (Figure 4-60) and window U-value (Figure 4-60). The reason for this difference is explained in Section 4.13.1 Electric. Figure 4-70 and Figure 4-71 show the chilled water consumption for the system with the economizer and the system without the economizer. These two systems have different patterns of chilled water consumption in cold OATs. Figure 4-72 demonstrates this with solid data evidence.

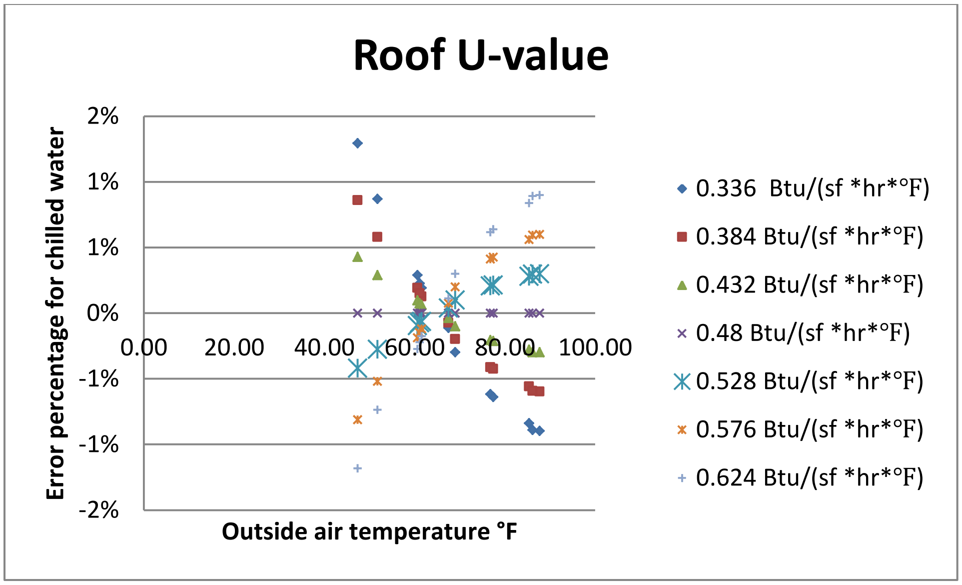
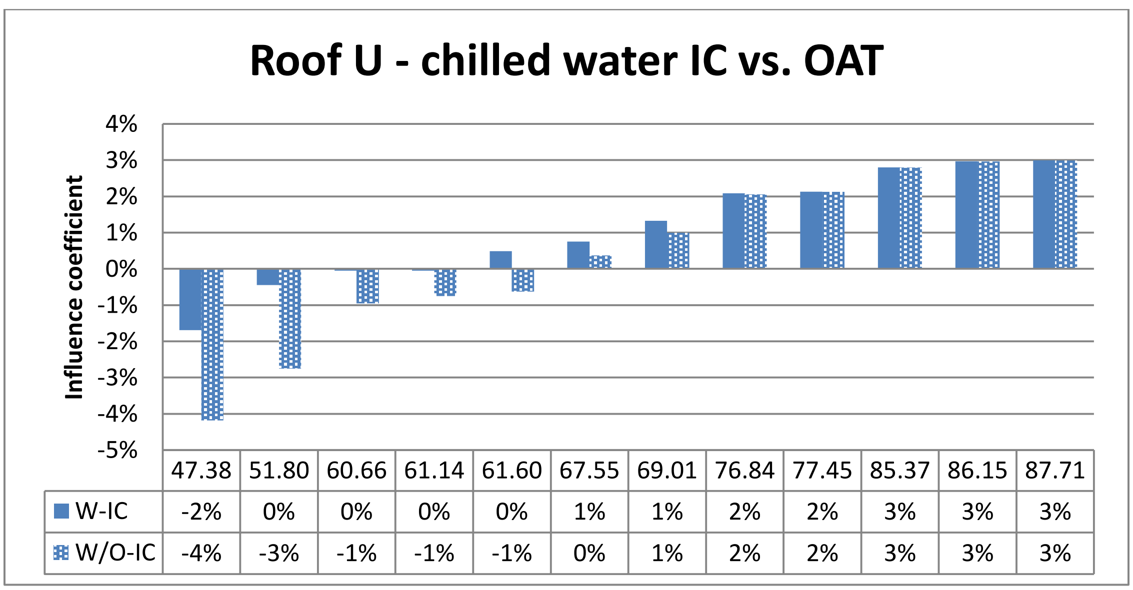



**Figure 4-71** Chilled water consumption for the parameter roof U, SDVAV without the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | -2% | 0% | 0% | 0% | 0% | 1% | 1% | 2% | 2% | 3% | 3% | 3% |
| W/O-IC | -4% | -3% | -1% | -1% | -1% | 0% | 1% | 2% | 2% | 3% | 3% | 3% |

**Figure 4-72** Chilled water consumption IC value for the parameter Roof U

4.13.3 Hot water

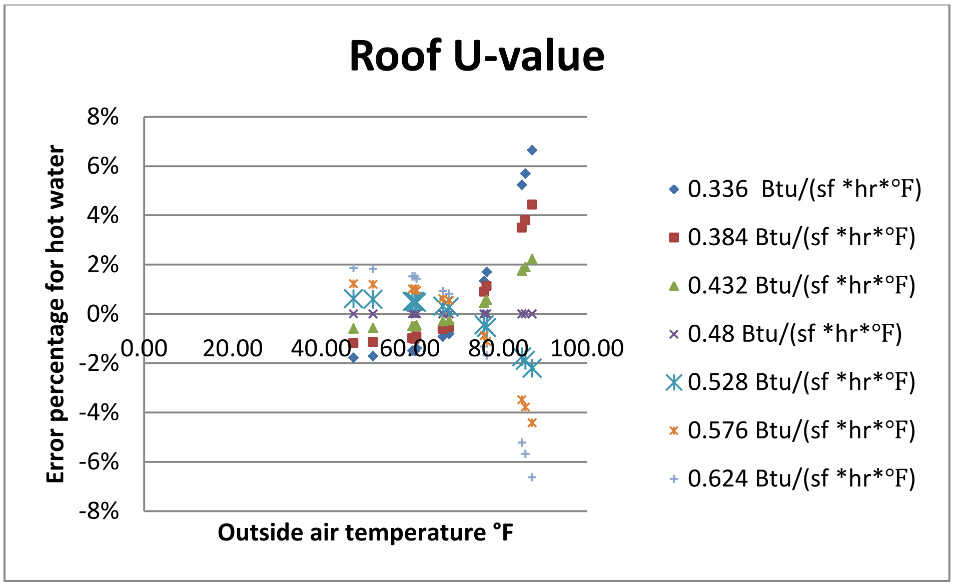
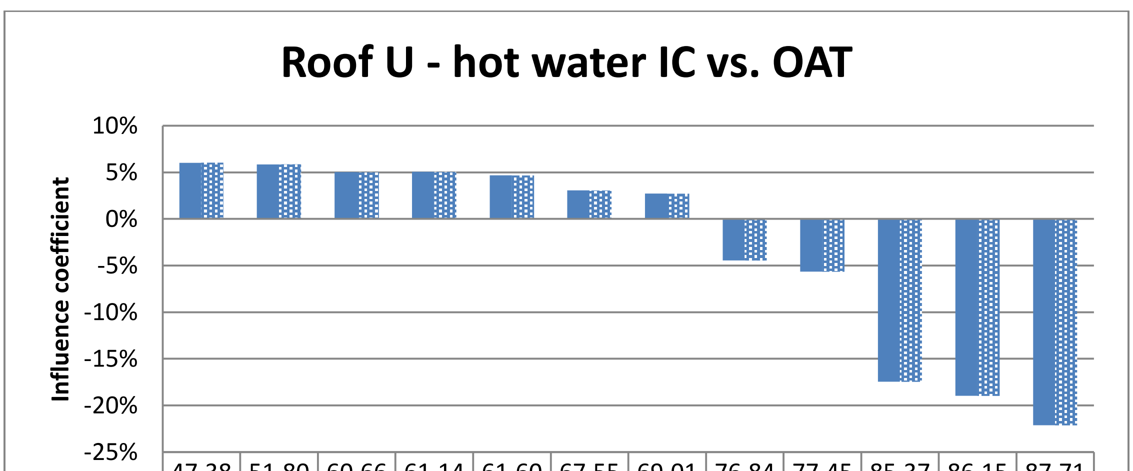



**Figure 4-73** Hot water consumption for the parameter roof U, SDVAV with the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 6% | 6% | 5% | 5% | 5% | 3% | 3% | -4% | -6% | -17% | -19% | -22% |
| W/O-IC | 6% | 6% | 5% | 5% | 5% | 3% | 3% | -4% | -6% | -17% | -19% | -22% |

**Figure 4-74** Hot water consumption IC value for the parameter roof U

Figure 4-73 shows the results for hot water consumption at different roof U-value adjustments. Figure 4-74 indicates that the effects of adjusting the roof U-value are the same for both the system with the economizer and the system without the economizer. The effect on hot water consumption made by adjusting the roof U-value can be explained in the opposite way compared with its effect to electric.

### 4.14 Peak occupancy (Occ)

Peak occupancy parameter shows the average area per person, in this way the higher this parameter is the less the number of people will be in the zone.

4.14.1 Electric

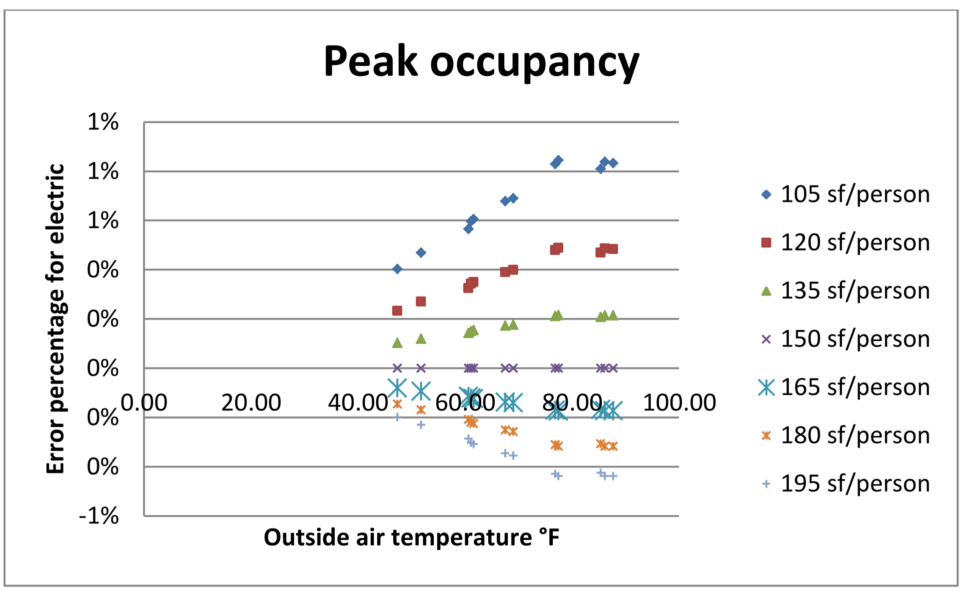



**Figure 4-75** Electric consumption for the parameter Occ, SDVAV with the economizer

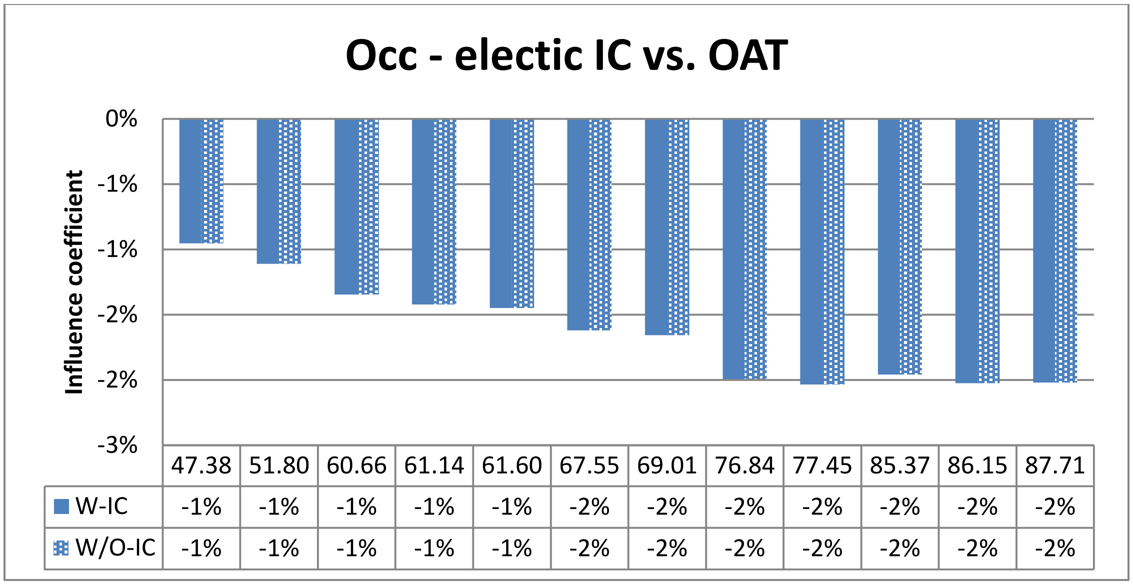



**Figure 4-76** Electric consumption IC value for the parameter Occ

Figure 4-75 implies that when the peak occupancy parameter is increased, the electric consumption will be reduced. Figure 4-76 shows that the effect to the electric influence coefficient caused by adjusting the occupancy parameter is the same in both the system with the economizer and the system without the economizer. Occupancy loads will affect the interior heat gain; the lower the peak occupancy parameter value is, the less the heat gain. From Equation 4-1 $Q_{cooling\ coil}$ is decreased because of increasing the peak occupancy parameter. Meanwhile, the $\Delta T_{\ fan}$ is constant, so the only way to balance this equation is to reduce the $\dot{V}$. From Equation 4-2 to Equation 4-4, decreasing the flow rate means decreasing the actual fan power, that is why the electric consumption will be decreased.

4.14.2 Chilled water

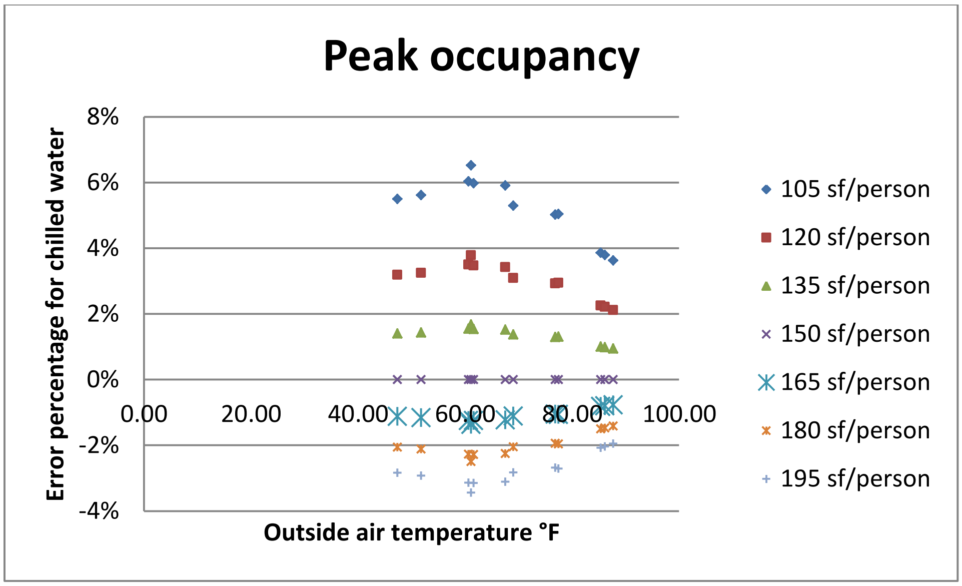
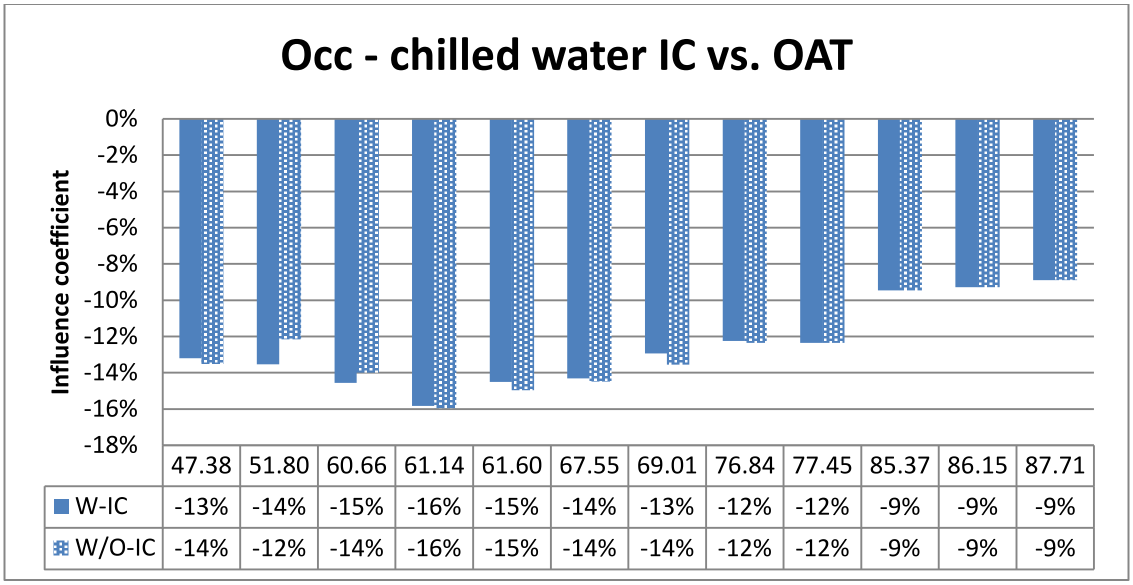



**Figure 4-77** Chilled water consumption for the parameter Occ, SDVAV system with the economizer

A similar physical explanation to that used in electric consumption for adjusting the occupancy parameter can be applied to chilled water consumption. When increasing the peak occupancy parameter, the peak value for the people in this zone will be reduced. In this way, the heat gain in this zone will be reduced, so the chilled water consumption will be reduced, see Figure 4-77. The influence coefficients at different adjustment for this parameter are shown in Figure 4-78.




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | -13% | -14% | -15% | -16% | -15% | -14% | -13% | -12% | -12% | -9% | -9% | -9% |
| W/O-IC | -14% | -12% | -14% | -16% | -15% | -14% | -14% | -12% | -12% | -9% | -9% | -9% |

**Figure 4-78** Chilled water consumption IC value for the parameter Occ

4.14.3 Hot water

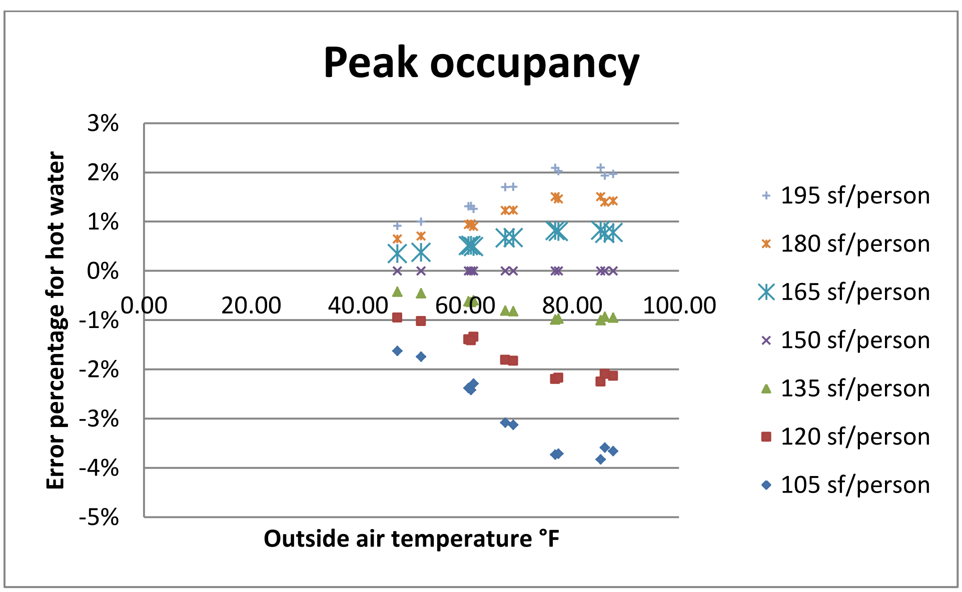
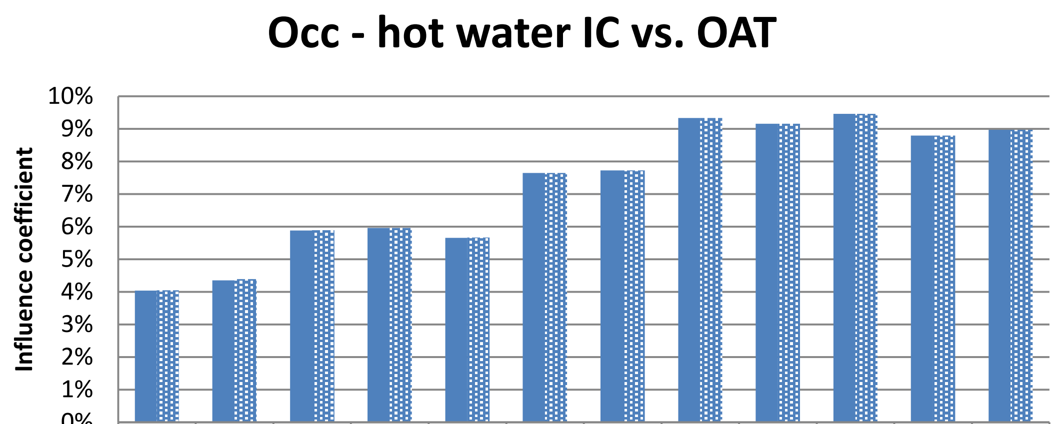



**Figure 4-79** Hot water consumption for the parameter Occ, SDVAV system with the economizer




| | 47.38 | 51.80 | 60.66 | 61.14 | 61.60 | 67.55 | 69.01 | 76.84 | 77.45 | 85.37 | 86.15 | 87.71 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| W-IC | 4% | 4% | 6% | 6% | 6% | 8% | 8% | 9% | 9% | 9% | 9% | 9% |
| W/O-IC | 4% | 4% | 6% | 6% | 6% | 8% | 8% | 9% | 9% | 9% | 9% | 9% |

**Figure 4-80** Hot water consumption IC value for the parameter Occ

Figure 4-79 and Figure 4-80 show that the impact to the hot water consumption by the peak occupancy parameter is the same for the system with the economizer and the system without the economizer. The more people in the zone, the more heat gain the system will receive and the less hot water will be required.

# 5. CALIBRATION TASK

## 5.1 Austin City Hall

5.1.1 Background (Zhou et al. 2009)

For this project, two software programs were used to model the same project. One is modeled by eQUEST 3.64 and the other is modeled by WinAM 4.3. The purpose for simulating two models is to have the eQUEST 3.64 model as the comparison model. There are two reasons for choosing eQUEST 3.64: 1) eQUEST 3.64 is one of the most popular software programs for building performance simulation, and 2) Compared with WinAM 4.3, the interface of eQUEST 3.64 is simpler.

Austin City Hall is located in downtown Austin, Texas. All of the information generated from this project is mainly based on the Continuous Commissioning® (CC®) report and some of the information comes from the discussion with the engineer who did the CC® project for Austin City Hall.

There are four floors in Austin City Hall. The total area is approximately 115,000 square feet. The envelope information for this building is in Table 5-1.

**Table 5-1** Envelope information of Austin City Hall

| Item | Content |
|---|---|
| U-value of the wall | $0.151 \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |
| U-value of the roof | $0.048 \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |
| U-value of  the window | $0.75 \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |

There are ten AHUs in this building. The hot water comes from the boiler on site. The efficiency of the boiler is approximately 80%. The chilled water used in the HVAC system is purchased. The chilled water pump power and the hot water pump power are 20 horsepower separately. The extra energy consumed here is used by the exhaust fan and the lighting in the parking garage. The energy consumed by the lighting in the parking garage is approximately 63 kW from 6:00 p.m. to 6:00 a.m. The exhaust fan power usage documented in the report is 300 kW. If the reduction factor of 0.4 is applied to the fan, 120 kW should be used in WinAM 4.3.

The general information for the air side system is offered in Table 5-2.

**Table 5-2** Air side system information of Austin City Hall

| Item | Content |
|---|---|
| Space temperature setpoint | 72°F |
| Minimum primary flow | $0.2\ \mathrm{CFM/ft^2}$ |
| Maximum primary flow | $1.1\ \mathrm{CFM/ft^2}$ |
| Minimum outside airflow | 20% |
| Preheat coil setpoint | When the OAT is lower than 55°F, the preheat coil temperature setpoint will be 69°F. |
| Precool coil setpoint | 55°F |
| Cooling coil reset schedule | When the OAT is higher than 70°F, the cooling coil's high limitation should be 55°F.<br>When the OAT is lower than 40°F, the cooling coil's low limitation should be 65°F. |
| Fan power | $0.85\ \mathrm{HP/kCFM}$ |
| Peak weekly lighting usage | $1.4\ \mathrm{W/ft^2}$ |
| Peak weekly plug load | $0.75\ \mathrm{W/ft^2}$ |

**Table 5-2** continued

| Item | Content |
|---|---|
| Nighttime lighting and plug load ratio | 0.2 |
| Weekday peak load ratio | 1 |
| Weekend peak load ratio | 0.3 |
| Weekday operating hours for lighting and plug | 8:00 a.m. to 5:00 p.m. |

To simplify the modeling process, ten AHUs in Austin City Hall will be divided into three groups based on system type and operation schedule. AHU 1, 2, 3, 4, 5, 6, 7 and 9 are Single Duct Variable Air Volume AHUs (SDVAV). AHU 8 and 10 are Single Zone Single Duct Constant Air Volume AHUs (SZSDCAV). The schedules for AHU 1, 9 and AHU 2, 3, 4, 5, 6, 7 are different. Under these conditions, there will be three different AHU groups. AHU Group 1 includes AHU 1 and AHU 9. AHU Group 2 includes AHU 8 and AHU 10. AHU Group 3 includes AHU 2, 3, 4, 5, 6, and 7.
The remaining information for each AHU group is in Table 5-3, Table 5-4, and Table 5-5.

**Table 5-3** AHU Group 1: AHU 1 and AHU 9 of Austin City Hall

| Category | Item | Content |
|---|---|---|
| Building envelope information | Conditioned floor area | 16% of the total building area |
| | Interior zone percentage | 85% |
| | Exterior wall and window area | 3654 $ft^2$ |
| | Window percentage | 15% |
| | Roof area | 0 $ft^2$ |

**Table 5-3** continued

| Category | Item | Content |
|---|---|---|
| Schedules and loads | Normal weekday schedule for AHUs | 24/7 |
| | Normal weekend schedule for AHUs | 24/7 |
| | Peak weekly occupancy | 50 $\text{ft}^2/\text{person}$ |
| | Weekday operating hours for lighting and plug | 12:00 p.m. to 3:00 p.m. |

**Table 5-4** AHU Group 2: AHU 8 and AHU 10 of Austin City Hall

| Category | Item | Content |
|---|---|---|
| Building envelope information | Conditioned floor area | 6% of total building area |
| | Interior zone percentage | 25% |
| | Exterior wall and window area | 2772 $\text{ft}^2$ |
| | Window percentage | 25% |
| | Roof area | 0 $\text{ft}^2$ |
| Schedule and load | Normal weekday schedule for AHUs | 12:00 a.m. to 5:30 a.m. |
| | Normal weekend schedule for AHUs | off |
| | Peak weekly occupancy | 40 $\text{ft}^2/\text{person}$ |
| | Weekday operating hours for lighting and plug | off |

**Table 5-5** AHU Group 3: AHU 2, 3, 4, 5, 6, and 7 of Austin City Hall

| Category | Item | Content |
|---|---|---|
| Building envelope information | Conditioned floor area | 78% of total building area |
| | Interior zone percentage | 75% |
| | Exterior wall and window area | 37926 $\text{ft}^2$ |
| | Window percentage | 55% |
| | Roof area | 34020 $\text{ft}^2$ |
| Schedule and load | Normal weekday schedule for AHUs | 6:00 a.m. to 10:00 p.m. |
| | Normal weekend schedule for AHUs | off |

**Table 5-5** continued

| Category | Item | Content |
|---|---|---|
| Schedule and load | Peak weekly occupancy | 130 $\mathrm{ft}^2/\mathrm{person}$ |
| | Weekday operating hours for lighting and plug | off |

5.1.2 Modeling process

5.1.2.1 Base models for eQUEST 3.64 and WinAM 4.3

a. WinAM 4.3 model

Create WinAM 4.3 model "a.1winbasemodel" based on the information mentioned previously.

b. Create eQUEST 3.64 model "a.1eQUEST3.64basemodel"

Some of the information cannot be applied to eQUEST 3.64 directly, because some options in eQUEST 3.64 are not exactly the same as in WinAM 4.3. Under this condition, multiple changes are required to model Austin City Hall in eQUEST 3.64. The following is a general summary of the differences between eQUEST 3.64 and WinAM 4.3 on the Austin City Hall project.

- Zone assignment

  In WinAM 4.3, the zone will be assigned based on the different percentage of exterior or interior zone. Figure 5-1 denotes in eQUEST 3.64 the exterior zone is from the exterior wall to the inner space with the user deciding the depth.

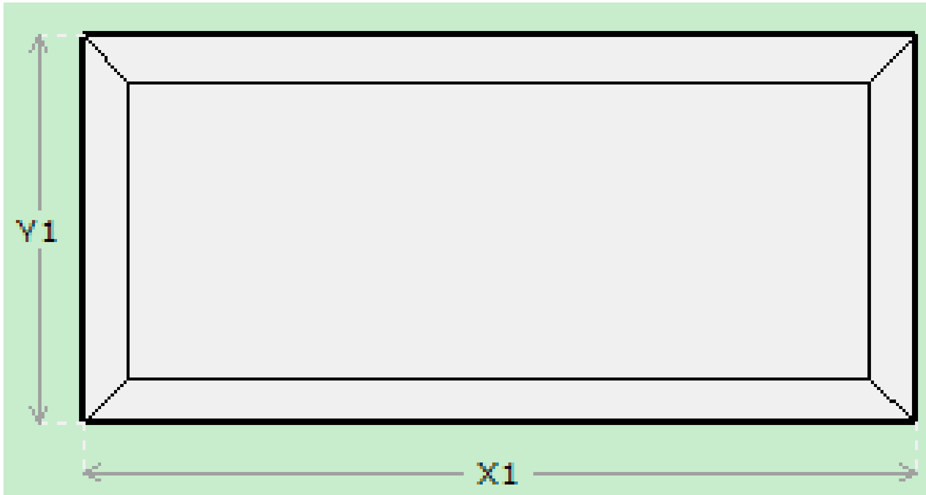


**Figure 5-1 eQUEST 3.64 zone assignment**

- Thermal mass

  eQUEST 3.64 asks for thermal mass, while WinAM 4.3 only asks for R-value. To make eQUEST 3.64 run the material with the lowest specific heat, the library has been chosen. The roof gravel has a specific heat of 0.4 $\frac{\mathrm{Btu}}{\mathrm{lb}} * °\mathrm{F}$ and a thickness of 0.5 ft.

- Window

➢ Glass transmittance

eQUEST 3.64 requires glass visible transmittance and the shading coefficient for completing the windows' inputs, while WinAM 4.3 only requires the U-value.

➢ Window area

eQUEST 3.64 asks for the window area for each wall, while WinAM 4.3 requires the window percentage for each AHU. In eQUEST 3.64 window areas of 42.7%

for each wall will be used. The window area for each AHU group in WinAM 4.3 has been discussed in Table 5-3, Table 5-4 and Table 5-5.

- Plenum

  eQUEST 3.64 requires the users to consider plenum. WinAM 4.3 does not have this option.

- Preheat

➢ eQUEST 3.64 asks for the $\Delta T$ (the temperature difference between before and after the hot water goes through the reheat coil) , while the reheat temperature for WinAM 4.3 will be as high as what is needed to meet the needs of the heating load.

➢ Austin City Hall requires preheat reset in the real project. WinAM 4.3 can achieve this requirement easily by using the preheat coil reset. The "Building Creation Wizard" level of eQUEST 3.64 only supports the constant preheating option.

- Outside airflow rate

  The outside airflow rate in eQUEST 3.64 has been set to default based on the different activity area. In WinAM 4.3 the user can decide it themselves.

- System assignment

  eQUEST 3.64 allows the users to have at most 2 systems and 3 schedules for each system in the basic level. WinAM 4.3 has only one schedule for each certain system, but more than 2 systems can be assigned. This makes the schedule assignment for the two programs significantly different from each other.

5.1.2.2 Apply CC® measures to eQUEST 3.64 and WinAM 4.3 model

The model without calibration and that has CC® measures has been named "a.2winbasemodel" in WinAM 4.3 and "a.2eQUEST3.64basemodel" in eQUEST 3.64. The CC® measures that have been applied to both the WinAM 4.3 and eQUEST 3.64 models are listed in Table 5-6.

**Table 5-6** CC® measures for Austin City Hall

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Outside airflow% | All | 20% | 10% |
| Minimum airflow rate | All | 0.2 CFM/ft$^2$ | 0.14 CFM/ft$^2$ |
| Economizer | All | None | 37°F to 64°F |
| Preheat | All | 69°F | 45°F |
| Minimum airflow rate | AHU Group1 | 0.2 CFM/ft$^2$ | If it is in the occupied mode, the minimum should be 0.14 CFM/ft$^2$. If it is in the unoccupied mode, the minimum should be 0 CFM/ft$^2$. |

Due to the properties of WinAM 4.3, some CC® measures cannot be applied to the simulated project. Demand-controlled ventilation using $CO_2$ sensors, static pressure reset and others are measures that cannot be applied. These measures can be the reason that the simulated data does not agree with the measured data.

5.1.2.3 Calibrate WinAM 4.3 model

Measured data is used to calibrate the WinAM 4.3 model. The same calibration steps that have been used in the WinAM 4.3 model are applied to eQUEST 3.64 models. The calibrated WinAM 4.3 model is named “b.1winbasemodel”. The calibrated eQUEST 3.64 model is named “b.1eQUEST3.64basemodel”. The method to generate weather data for WinAM 4.3 and eQUEST 3.64 has been discussed in Section 3 and Appendix A. The detailed calibration steps are shown in Table 5-7.

**Table 5-7** Calibration for Austin City Hall

| Item | AHU Group | Before Calibration | After Calibration |
|---|---|---|---|
| Non-HVAC electric usage (24/7) | All | 120 kW | 140 kW |
| Minimum airflow rate | AHU Group 1 | 0.2 CFM/ft$^2$ | 0.4 CFM/ft$^2$ |
| | AHU Group 3 | 0.2 CFM/ft$^2$ | 0.4 CFM/ft$^2$ |
| Cooling coil reset | AHU Group 1 | Temperature setpoint for the lower OAT is 65°F. | Temperature setpoint for the lower OAT is 60°F |
| | AHU Group 3 | Temperature setpoint for the lower OAT is 65°F. | Temperature setpoint for the lower OAT is 60°F |
| Peak plug load | All | 1 W/ft$^2$ | 1.5 W/ft$^2$ |
| Outside airflow percentage | All | 20% | 25% |
| Peak Occupancy | AHU Group 1 | 50 ft$^2$/person | 100 ft$^2$/person |
| | AHU Group 2 | 30 ft$^2$/person | 60 ft$^2$/person |
| | AHU Group 3 | 130 ft$^2$/person | 100 ft$^2$/person |
| Humidity upper limitation | AHU Group 2 | 65% | 60% |

5.1.2.4 Apply CC® measures to the calibrated model

The same CC® measures documented in Section 5.1.2.2 are applied to the WinAM 4.3 model and eQUEST 3.64 model “b.1winbasemodel” and “b.1eQUEST 3.64basemodel”. The new model WinAM 4.3 model is named “b.2winbasemodel”. The new eQUEST 3.64 model is named “b.2eQUEST3.64basemodel”.

## 5.2 Dallas/Fort Worth (DFW) International Airport Terminal D

5.2.1 Background (ESL 2010a)

Dallas/Fort Worth (DFW) International Airport Terminal D is a 160,000 square foot building. It has a special structure inside such that there is no complete floor between the second floor and the third floor. Figure 5-2 shows the inside of the building structure from the north. Figure 5-3 is the west facing chart.

The challenge for modeling this project in WinAM 4.3 is that the area served by each AHU is not documented in the CC® report. A solution that allows for analysis is to sum the maximum airflow rate from each terminal box for the separated AHU. Then the percentage of each AHU group’s total maximum airflow rate is calculated for comparison with the total airflow rate supplied to this building.

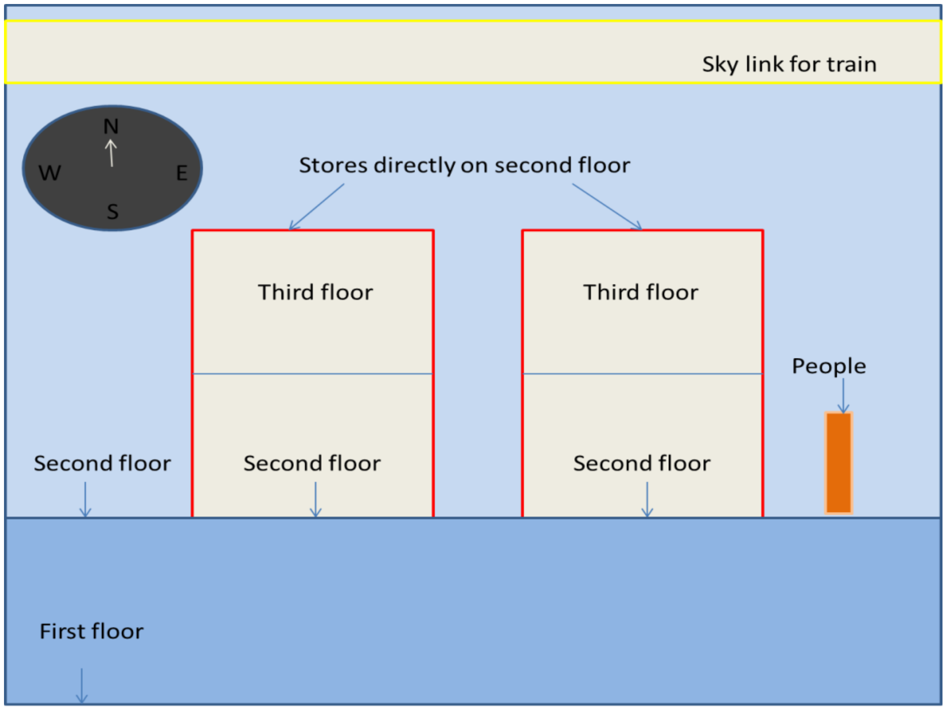



**Figure 5-2** Internal structure of the north face of Terminal D

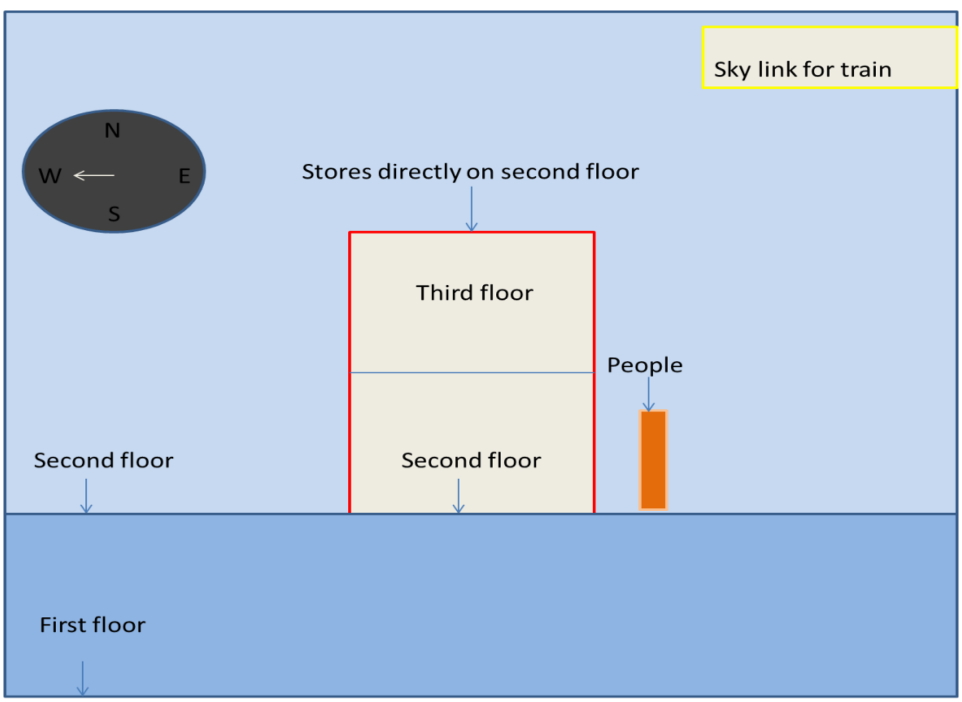



**Figure 5-3** Internal structure of the west face of Terminal D

DFW is served by VAV AHUs, SDCAV AHUs and Outside Air AHUs. The outside air that supplies the VAV AHUs and CAV AHUs comes from the Outside Air AHUs. Based on the Continuous Commissioning® of Terminal D DFW International Airport Final Report for September 2010, there are two AHU groups for the WinAM 4.3 model. The cooling and heating resource come from the plant on site. The envelope information is in Table 5-8.

**Table 5-8** Envelope information of DFW Terminal D

| Item | Content |
|---|---|
| U-value for wall | $0.151\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| U-value for roof | $0.048\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| U-value for window | $0.75\ \mathrm{Btu/(hr * ft^2 * °F)}$ |

The general information for the air side system is in Table 5-9:

**Table 5-9** Air side system data of DFW Terminal D

| Item | Content |
|---|---|
| Space setpoint | 72°F |
| Minimum primary airflow rate | $0\ \mathrm{CFM/ft^2}$ |
| Maximum primary airflow rate | $2.15\ \mathrm{CFM/ft^2}$ |
| Preheat coil setpoint | 40°F |
| Precool coil setpoint | 55°F |
| Fan power | $0.8\ \mathrm{HP/kCFM}$ |
| AHU schedule | Occupied: 5:00 a.m. to 10:00 p.m.<br>Unoccupied: 10:00 p.m. to 5:00 a.m. |
| Peak weekly lighting usage | $1.5\ \mathrm{W/ft^2}$ |

**Table 5-9** continued

| Item | Content |
|---|---|
| Peak weekly plug load | 0.7 $\mathrm{W/ft^2}$ |
| Peak weekly occupancy | 333 $\mathrm{ft^2/person}$ |
| Nighttime lighting and plug load ratio | 0.2 |
| Weekday peak load ratio | 1 |
| Weekend peak load ratio | 1 |
| Weekday operating hours for lighting and plug | 7:00 a.m. to 8:00 p.m. |
| Weekend operating hours for lighting and plug | 7:00 a.m. to 8:00 p.m. |

The AHUs in this project have been divided into two groups. The information for AHU Group 1 is in Table 5-10; the information for AHU Group 2 is in Table 5-11.

**Table 5-10** AHU Group 1: VAV AHUs of DFW Terminal D

| Category | Item | Content |
|---|---|---|
| Building envelope information | Conditioned floor area | 70% of total building area |
| | Interior zone percentage | 75% |
| | Exterior wall and window area | 170990 $\mathrm{ft^2}$ |
| | Window percentage | 70% |
| | Roof area | 414867 $\mathrm{ft^2}$ |
| Schedules and loads | Normal weekday schedule for AHUs | 24/7 |
| | Normal weekend schedule for AHUs | 24/7 |

**Table 5-10** continued

| Category | Item | Content |
|---|---|---|
| Secondary system | Cooling coil setpoint | When the OAT is higher than 65°F, the cooling coil high temperature limitation should be 55°F.<br>When the OAT is lower than 45°F, the cooling coil temperature low limitation should be 60°F. |
| | Minimum OA flow | Unoccupied: 0%<br>Occupied: 26% |

**Table 5-11** AHU Group 2: SDCAV AHUs of DFW Terminal D

| Category | Item | Content |
|---|---|---|
| Building envelope information | Conditioned floor area | 30% of total building area |
| | Interior zone percentage | 75% |
| | Exterior wall and window area | 73281 $ft^2$ |
| | Window percentage | 70% |
| | Roof area | 177800 $ft^2$ |
| Schedules and loads | Normal weekday schedule for AHUs | 24/7 |
| | Normal weekend schedule for AHUs | 24/7 |
| Secondary system | Cooling coil setpoint | 55°F |
| | Minimum OA flow | Unoccupied: 0%<br>Occupied: 15% |

5.2.2 Modeling process

5.2.2.1 Base model for WinAM 4.3

The base model is simulated as WinAM 4.3 model “a.1basemodel” according to the information collected above.

5.2.2.2 Apply CC® measures to WinAM 4.3 model

CC® measures are applied to “a.1basemodel” and the new model is named “a.2basemodel”. The CC® measures for this project are listed in Table 5-12.

**Table 5-12** CC® measures of DFW Terminal D

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Minimum airflow rate | All | 0.14 $\mathrm{CFM/ft^2}$ | Add the occupied /unoccupied mode, so the minimum airflow rate can be 0 $\mathrm{CFM/ft^2}$. |
| Cooling coil reset | All | 55 $\mathrm{CFM/ft^2}$ | When the OAT is lower than 45°F, the cooling coil temperature setpoint is 60°F. When the OAT is higher than 65°F, the cooling coil temperature setpoint is 55°F. |

Although in Table 5-12 there are only two CC® measures applied to the WinAM 4.3 simulated model, more CC® measures have been applied to this project. WinAM 4.3 cannot model these additional measures. The reason is that the improvement measures are different for each single AHU, and in this project there are 15 different improvements that have been applied to more than 50 AHUs.

5.2.2.3 Calibrate WinAM 4.3 model

Model “b.1 basemodel” is calibrated based on the measured data. The calibration steps are listed in Table 5-13.

**Table 5-13** Calibration steps for DFW Terminal D

| Item | AHU Group | Before Calibration | After Calibration |
|---|---|---|---|
| Minimum airflow rate $\mathrm{CFM/ft^2}$ | AHUVAV | 0.14 $\mathrm{CFM/ft^2}$ | 0.8 $\mathrm{CFM/ft^2}$ |
| Outside airflow % | AHUVAV | 26% | 20% |
| Peak plug load $W/ft^2$ | All | 0.75 $W/ft^2$ | 1 $W/ft^2$ |
| Night plug load ratio | All | 0.2 | 0.35 |

After the calibration, the new calibrated base model is renamed as “b.1basemodel”.

5.2.2.4 Apply CC® measures to the calibrated model

Apply the same CC® measures to the calibrated base model “b.1basemodel”, and name this new model “b.2basemodel”.

## 5.3 DFW International Airport Rent-A-Car Center

### 5.3.1 Background (Zeig et al. 2004)

The DFW International Airport Rent-A-Car Center has an area of 130,000 square feet with two stories. The building attached to it is the two-story parking garage. Both of the buildings run 24/7. Although the parking garage building is not air-conditioned, it is one of the top 3 power consuming facilities in the DFW International Airport because the lighting in the garage is always on. There are six SDVAV AHUs named from AHU1 to AHU6, and more than 133 terminal boxes serve this building. In the WinAM 4.3 model, these six AHUs will be combined into one AHU group, because they have the same system and similar performance. Compared with the other AHUs, AHU 4 and AHU 5 have different static pressure. Since WinAM 4.3 cannot model statistic pressure, they are still grouped with the other AHUs.

The general information for this project is in Table 5-14:

**Table 5-14** General information for DFW Rent-A-Car Center

| Category | Item | Content |
|---|---|---|
| Envelope | U-value for wall | $0.151\ \mathrm{Btu/(hr * ft^2 * {}^\circ F)}$ |
| | U-value for roof | $0.048\ \mathrm{Btu/(hr * ft^2 * {}^\circ F)}$ |
| | U-value for window | $0.75\ \mathrm{Btu/(hr * ft^2 * {}^\circ F)}$ |
| | Conditioned floor area | $130000\ \mathrm{ft^2}$ |
| | Interior zone percentage | 80% |

**Table 5-14** continued

| Category | Item | Content |
|---|---|---|
| Envelope | Roof Area | 65000 $\mathrm{ft}^2$ |
| | Exterior wall and window area | 37082 $\mathrm{ft}^2$ |
| | Window percentage | 30% |
| First system | Chiller efficiency | 0.655 $\mathrm{kW/ton}$ |
| | Chilled water pumping power | 74 HP |
| Second system | Minimum airflow | 0.36 $\mathrm{CFM/ft^2}$ |
| | Maximum airflow | 1.2 $\mathrm{CFM/ft^2}$ |
| | Minimum outside airflow percentage | 30% |
| | Preheat coil setpoint | 45°F |
| | Cooling coil setpoint | 55°F |
| | Space setpoint | 73°F |
| | Supply fan power | 0.8 $\mathrm{HP/kCFM}$ |
| | Return fan power | 0.4 $\mathrm{HP/kCFM}$ |
| Internal loads | Peak weekly occupancy | 83 $\mathrm{ft^2/person}$ |
| | Peak weekly lighting usage | 1 $\mathrm{W/ft}$ |
| | Peak weekly plug load | 1.2 $\mathrm{W/ft}$ |
| | Nighttime lighting and plug load ratio | 0.8 |
| | Weekday peak load ratio | 1 |
| Schedule | Lighting and plug weekday operating hours | 24/7 |
| | Lighting and plug weekend operating hours | 24/7 |
| | AHU weekday schedule | 24/7 |
| | AHU weekend schedule | 24/7 |

Suppose this project operates 12 hours in the daytime. The total load of the second level in the south garage has been reduced to approximately 46.3 kW/day when the light is turned off during the day. That denotes that the full lighting load for the south garage is approximately twice the 46.3 kW/day. For simplification, 100 kW/day will be used instead of 92.6 kW/day. It is the same with the other garages. We assume the lighting load for each garage is 100 kW/day during the nighttime. The remaining energy cost is caused by plug loads which run 24/7.

We know the lighting for the south garage is always on before applying CC® measures.

According to the assumptions made earlier, the garage lighting electric consumption is 100 kW/day, so three garages will operate 300 kW over the entire day. By subtracting the lighting consumption power from the total electric consumption of 540.8 kW/day, the plug load consumption of 240.8 kW/day is estimated.

We assume the lighting affect for the total energy is $\frac{46.3}{2}\,\mathrm{kW/day}$ =23 kW/day

So the total non-HVAC electric usage is (240.8+23) kW/day= 263.8 kW/day

### 5.3.2 Modeling process

#### 5.3.2.1 Base model for WinAM 4.3

The basic WinAM 4.3 model named “a.1basemodel” is simulated according to the information offered above.

5.3.2.2 Apply CC® measures to WinAM 4.3 model

CC® measures are applied to “a.1basemodel” and the new model is named “a.2basemodel”.

Many CC® measures have been applied to this project. Many of them cannot be modeled by WinAM 4.3. Table 5-15 contains the CC® measures that have been applied to the WinAM 4.3 model, and Table 5-16 are those measures that cannot be modeled by WinAM 4.3.

**Table 5-15** CC® measures for DFW Rent-A-Car Center

| Component | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Outside airflow percentage | All | 40% | 15% |
| Cooling coil reset | All | 55°F | When the OAT is lower than 40°F, the cooling coil temperature setpoint is 62°F. When the OAT is higher than 75°F, the cooling coil temperature setpoint is 55°F. |
| Reschedule non-HVAC electric usage | None | 263.8 kW | 240.8 kW |
| Minimum airflow | All | 0.36 CFM | 0.2 CFM |

**Table 5-16** CC® measures that cannot be applied to DFW Rent-A-Car Center

| Component | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Static Pressure Reset | AHU 1,2,3,6 | | When the OAT is lower than 50°F, the static pressure is 0.5 inch of water. When the OAT is higher than 80°F, the static pressure is 0.8 inch of water. |
| | AHU 4, 5 | | When the OAT is lower than 50°F, the static pressure is 0.5 inch of water. When the OAT is higher than 80°F, the static pressure is 1 inch of water. |
| Chiller operation reset | | Didn't mention in the report | When the OAT is higher than 57°F, the new control of sequence was added to the chiller to enable the chiller even when the vent cycle is off. |
| Chiller temperature reset | | Didn't mention in the report | When the OAT is lower than 50°F, the chilled water temperature is 48°F. When the OAT is higher than 70°F, the chilled water temperature is 42°F. |
| Condenser water temperature reset | | 85°F | When the outside wet bulb temperature is lower than 62°F, the condenser water temperature is 70°F. When the OAT is higher than 77°F, the condenser water temperature is 85°F. |
| Secondary pump control reset | | 12 psi | The maximum differential pressure setpoint is 4 psi when the OAT is lower than 55°F and 8 psi when the OAT is higher than 80°F. |

5.3.2.3 Calibrate WinAM 4.3 model

The model “a.1basemodel” is calibrated based on the measured data and is named “b.1basemodel”. The calibration steps are listed in Table 5-17.

**Table 5-17** Calibration for DFW Rent-A-Car Center

| Component | AHU Group | Before Calibration | After Calibration |
|---|---|---|---|
| Outside airflow percentage | All | 40% | 25% |
| Peak plug load | All | $1.2\ \mathrm{W/ft^2}$ | $1.7\ \mathrm{W/ft^2}$ |
| Minimum airflow | All | $0.36\ \mathrm{CFM/ft^2}$ | $0.4\ \mathrm{CFM/ft^2}$ |
| Zone temperature | All | 73°F | 72°F |

5.3.2.4 Apply CC® measures to the calibrated model

The CC® measures that have been applied in 5.3.2.2 are applied to the calibrated WinAM 4.3 model “b.1basemodel”. The new model is named “b.2basemodel”.

## 5.4 DFW Terminal E

5.4.1 Background (ESL 2010c)

This project was performed before December 2010. Sky link is the main construction in Terminal E of the Dallas/Ft. Worth airport. The total area of Terminal E is approximately 718,000 $\mathrm{ft}^2$.

Terminal E is served by 23 SDVAV VAHUs and 4 SDCAV AHUs. Sky link in Terminal E is served by 8 SDVAV AHUs, 4 SDCAV AHUs and approximately 120 terminal boxes. The assumption has been made that all of the SDVAV AHUs have approximately similar behavior because there is no more information about the remaining SDVAV AHUs. After discussion with the engineer who has worked for this project, the following important information was obtained: SDCAV AHUs were not involved in this CC® project and the communication room was not used when they applied CC® measures to this project. In this case, the AHUs in this project are SDVAV AHUs.

The chilled water and hot water come from the energy plaza on site. There are 4 pumps; each pump is 20 horsepower. Two are for the chilled water and the remaining are for hot water.

General information of this project is in Table 5-18:

**Table 5-18** General information of DFW Terminal E

| Category | Item | Content |
|---|---|---|
| Envelope | U-value for wall | $0.151\ \mathrm{Btu/(hr*ft^2*°F)}$ |
| | U-value for roof | $0.048\ \mathrm{Btu/(hr*ft^2*°F)}$ |
| | U-value for window | $0.75\ \mathrm{Btu/(hr*ft^2*°F)}$ |
| | Conditioned floor area | $781{,}000\ \mathrm{ft^2}$ |
| | Interior zone percentage | 40% |

**Table 5-18** continued

| Category | Item | Content |
|---|---|---|
| Envelope | Roof area | 351450 $ft^2$ |
| | Exterior wall and window area | 1,447,401 $ft^2$ |
| | Window percentage | 50% |
| First system | Chilled water pumping power | 24 HP |
| | Hot water pumping power | 24 HP |
| Second system | Supply fan power | 0.8 HP/kCFM |
| | Return fan power (SDVAV) | 0.1 HP/kCFM |
| Internal loads | Nighttime lighting and plug load ratio | 0.5 |
| | Weekday peak load ratio | 1 |
| Schedule | Lighting and plug weekday operating hours | 5:00 a.m. to 11:00 p.m. |
| | Lighting and plug weekend operating hours | 5:00 a.m. to 11:00 p.m. |
| | AHU weekday schedule | 24/7 |
| | AHU weekend schedule | 24/7 |
| Second System | Minimum airflow | 0.36 CFM/$ft^2$ |
| | Maximum airflow | 1.2 CFM/$ft^2$ |
| | Minimum outside airflow percentage | 20% |
| | Preheat coil setpoint | 52°F |
| | Cooling coil setpoint | 56°F |
| | Space setpoint | 62°F |
| | Supply fan power | 0.8 HP/kCFM |
| | Return fan power | 0.1 HP/kCFM |

**Table 5-18** continued

| Category | Item | Content |
|---|---|---|
| Internal Loads | Peak weekly occupancy | $333\ \mathrm{ft}^2/\mathrm{person}$ |
| | Peak weekly lighting usage | $1.4\ \mathrm{W/ft}$ |
| | Peak weekly plug load | $0.75\ \mathrm{W/ft}$ |
| | Nighttime lighting and plug load ratio | 0.5 |
| | Weekday peak load ratio | 1 |

5.4.2 Modeling process

5.4.2.1 Base model for WinAM 4.3

The basic WinAM 4.3 model “a.1basemodel” is simulated according to the information offered above.

5.4.2.2 Apply CC® measures to WinAM 4.3 model

The CC® measures are applied to “a.1basemodel” model. The new model is named “a.2basemodel”

There are several CC® measures applied to DFW Terminal E. Not all of them may be applied to the WinAM 4.3 simulated model. Table 5-19 shows the CC® measures that can be applied to the simulated model. Table 5-20 lists the CC® measures that cannot be applied to the simulated model.

**Table 5-19** CC® measures for DFW Terminal E

| Component | Before CC® Measures | After CC® Measures |
|---|---|---|
| AHU operation schedule | 24/7 | 3:30 a.m. to 11:00 p.m. |
| Occupied/Unoccupied mode | Does not have this | When it is unoccupied, change the minimum airflow from 0.36 CFM to 0 CFM |
| Cooling coil temperature reset | 56°F | When the OAT is lower than 40°F, the cooling coil temperature is 70°F. When the OAT is higher than 55°F, the cooling coil temperature is 61°F. When the OAT is higher than 80°F, the cooling coil temperature is 52°F. |
| Zone temperature | 62°F | Use 71.5°F |

**Table 5-20** CC® measures that cannot be applied to DFW Terminal E

| Component | Before CC® Measures | After CC® Measures |
|---|---|---|
| AHU operation strategy | 24/7 | 1. For the unoccupied space, only run AHUs when the space is out of temperature range.<br>2. Reduce AHU static pressure set-point when it is unoccupied or light occupied. |
| Zone temperature strategy | Occupied heating: 68°F<br>Unoccupied heating: 60°F<br>Occupied cooling: 71°F<br>Unoccupied cooling: 85°F | Occupied heating: 68°F<br>Unoccupied heating: 65°F<br>Occupied cooling: 73°F<br>Unoccupied cooling: 78°F |
| Airflow Strategy | Minimum airflow for cooling: 30% of design airflow<br>Minimum airflow for heating: 40% of design airflow | Minimum airflow for cooling: 0% of design airflow<br>Minimum airflow for heating: 30% of design airflow |

5.4.2.3 Calibrate WinAM 4.3 model

The model "a.1basemodel" is calibrated based on the measured data. The calibration process is in Table 5-21.

**Table 5-21 Calibration strategies for DFW Terminal E**

| Component | Before Calibration | After Calibration |
|---|---|---|
| Zone temperature | 62°F | 67.5°F |
| Maximum airflow | 1.2 CFM | 2 CFM |
| Peak plug load | 0.75 $\mathrm{w/ft^2}$ | 1.5 $\mathrm{w/ft^2}$ |
| Peak lighting load | 1.4 $\mathrm{w/ft^2}$ | 1.5 $\mathrm{w/ft^2}$ |
| U-value of the window | 0.75 $\mathrm{Btu/(hr * ft^2 * °F)}$ | 0.6 $\mathrm{Btu/(hr * ft^2 * °F)}$ |
| Minimum outside air | 20% | 15% |

5.4.2.4 Apply CC® measures to the calibrated model

The CC® measures used in Section 5.4.2.2 are applied to the calibrated WinAM 4.3 model. The calibrated model with CC® measures is named "b.2basemodel".

**5.5 Sunset Valley Elementary School**

5.5.1 Background (Yagua et al. 2009)

This project only has one floor and is designed on the "Pod Principle", as seen in Figure 5-4. The first 2 Pods, POD-1 and POD-2, plus the main POD were built in 1970. POD-3 was added in 1984 and POD-4 was added in 1996.

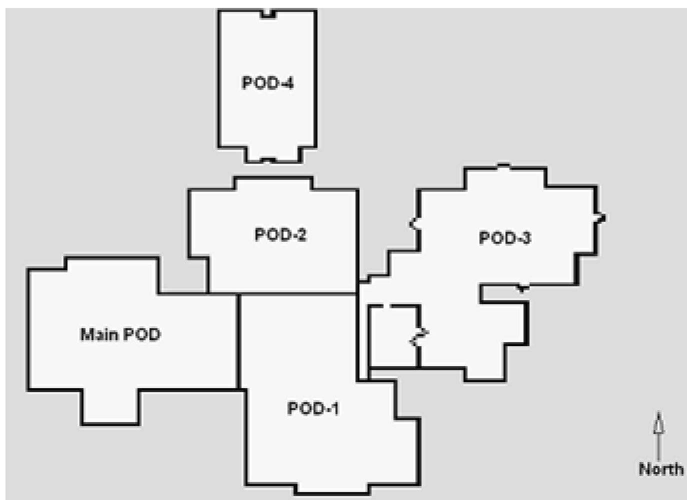



**Figure 5-4** Floor plan of Sunset Valley Elementary School

The total conditioned area is approximately 58,063 $ft^2$. Since it is an elementary school, it has classrooms, administrative offices, a gymnasium, a cafeteria, a kitchen, a library, storage area and restrooms. CC® measures have been implemented in this project since June 2009.

The envelope information of Sunset Valley Elementary School is in Table 5-22:

**Table 5-22** Envelope information of Sunset Valley Elementary School

| Component | Content |
|---|---|
| U-value for wall | $0.151\ \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |
| U-value for roof | $0.048\ \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |
| U-value for window | $0.75\ \mathrm{Btu}/(\mathrm{hr} * \mathrm{ft}^2 * {}^\circ\mathrm{F})$ |

There are four Dual Duct Constant Volume Multi-zone (DDCVM) AHUs and four Single Duct Constant Volume (SDCV) AHUs. All SDCV AHUs are located in the main POD. All of them have an economizer function. While after CC® measures the economizer function will be turned off for one DDCVM AHU. According to the different AHU type and control strategy applied to each AHU, they have been divided into three AHU groups in the simulated WinAM 4.3 model. AHU Group 1 contains DDCVM AHUs except the one without the economizer after CC® measures. AHU Group 2 contains this DDCVM AHU. AHU Group 3 contains all SDCV AHUs. Conditioned areas in WinAM 4.3 for the different AHU groups are assigned by which POD they serve.

The basic information for the first system is in Table 5-23:

**Table 5-23 First system information of Sunset Valley Elementary School**

| Item Name | Content | Reason |
|---|---|---|
| Electric cooling system efficiency (kW/ton) | 0.88 | Assumed |
| Gas heating system efficiency (%) | 80% | Assumed |

**Table 5-23** continued

| Item Name | Content | Reason |
| --- | --- | --- |
| Chilled water pumping | 42 HP | The report documents that the pumping system is 70 HP. The pumping system cannot work at 100% efficiency so multiply 0.6 with 70 HP to get the reasonable input for WinAM. |
| Hot water pumping | 6.9 HP | The report documents that the pumping system is 70 HP. The pumping system cannot work at 100% efficiency so multiply 0.6 with 11.5 HP to get the reasonable input for WinAM. |

General information about Sunset Valley Elementary School is in Table 5-24:

**Table 5-24** General information of Sunset Valley Elementary School

| Category | Item | Content |
| --- | --- | --- |
| Loads and schedule | Nighttime lighting and plug load ratio | 0 |
| | Weekday peak load ratio | 1 |
| | Weekend peak load ratio | 0 |
| | Weekday operating hours | 7:00 a.m. to 4:00 p.m. |
| | Weekend operating hours | 0 |
| | Peak weekly lighting usage | $1\ \mathrm{w/ft^2}$ |
| | Peak weekly plug load | $1.2\ \mathrm{w/ft^2}$ |
| | Peak weekly occupancy | $83\ \mathrm{ft^2/person}$ |

**Table 5-24** continued

| Category | Item | Content |
|---|---|---|
| Secondary system and schedule | Normal weekday schedule | 5:45 a.m. to 6:25 p.m. |
| | Normal weekend schedule | Off |
| | Special weekday schedule | Off |
| | Special weekend schedule | Off |
| | Airflow | $1\ \mathrm{CFM/ft^2}$ |
| | Economizer (temperature) | 45°F to 59°F |
| | Economizer maximum OA flow | 100% |
| | Hot deck coil setpoint/reset (only for DD) | 95°F |

In this project, AHUs have been divided into three groups. The information for these groups is given in Table 5-25, Table 5-26 and Table 5-27.

**Table 5-25** Information for AHU Group 1: DDCVM AHUs of Sunset Valley Elementary School

| Category | Item | Content |
|---|---|---|
| Envelope | Conditioned area | 40644 $\mathrm{ft^2}$ |
| | Interior zone percentage | 70% |
| | Exterior wall and window area | 14846 $\mathrm{ft^2}$ |
| | Window percentage | 30% |
| | Roof area | 40644 $\mathrm{ft^2}$ |
| Secondary system | Space setpoint | 70°F |
| | Minimum OA flow | 20% |
| | Precool coil setpoint/ reset | 52.5°F |

**Table 5-26** Information for AHU Group 2: DDCVM AHU (AHU-2) of Sunset Valley Elementary School

| Category | Item | Content |
|---|---|---|
| Envelope | Conditioned area | 5806 $ft^2$ |
| | Interior zone percentage | 60% |
| | Exterior wall and window area | 2206 $ft^2$ |
| | Window percentage | 30% |
| | Roof area | 5806 $ft^2$ |

**Table 5-27** Information for AHU Group 3: SDCV of Sunset Valley Elementary School

| Category | Item | Content |
|---|---|---|
| Envelope | Conditioned area | 17419 $ft^2$ |
| | Interior zone percentage | 80% |
| | Exterior wall and window area | 5012 $ft^2$ |
| | Window percentage | 30% |
| | Roof area | 17419 $ft^2$ |
| Secondary system | Space setpoint | 72°F |
| | Minimum OA flow | 100% |
| | Precool coil setpoint/reset | 55°F |

The way to distinguish different areas for different AHUs is based on the information offered by the CC® report. All of the DDCVM AHUs provide the conditioned air for POD 1, 2 and 3. And the four SDCV AHUs serve the library, the administrative area, the gymnasium and the cafeteria which are located in the main POD and POD-4.

### 5.5.2 Modeling process

#### 5.5.2.1 Base model for WinAM 4.3

The Sunset Valley Elementary School base model is simulated according to the information offered above. The name of the model is "a.1basemodel".

#### 5.5.2.2 Apply CC® measures to WinAM 4.3 model

The CC® measures are applied to model "a.1basemodel". The new model is named "a.2basemodel". The CC® measures in Table 5-28 are the measures which can be applied to WinAM 4.3.

**Table 5-28** CC® measures for Sunset Valley Elementary School

| Item | Before CC® Measures | After CC® Measures |
| --- | --- | --- |
| Hot deck (DDCAV) | 95°F | When the OAT is lower than 30°F, the hot water coil temperature is 100°F. When the OAT is higher than 70°Fh, the hot water coil temperature is 70°F. |
| Cold deck (DDCAV) | 52.5°F | When the OAT is lower than 40°F, the cold water coil temperature is 65°F. When the OAT is higher than 60°Fh, the cold water coil temperature is 55°F. |
| Economizer | All of the AHUs have economizers, and the temperature range for the SDCAV is 45°F to 59°F | Eliminate the economizer model for the DDCAVM AHU-2.<br>Operate the economizer for the SDCAV AHU in the temperature range of 40°F to 60°F6 |
| Chiller | Operate 24/7 | Improve the work schedule of the chiller from 24/7 to automatic control. |

Table 5-29 contains the CC® measures that cannot be applied to WinAM 4.3

**Table 5-29** CC® measures that cannot be applied to Sunset Valley Elementary School WinAM 4.3 model

| Item | Before CC® Measures | After CC® Measures |
|---|---|---|
| Boiler | Boiler will be enabled when the OAT is lower than 73°F. | Boiler will be enabled when the OAT is lower than 85°F. |

5.5.2.3 Calibrate WinAM 4.3 model

The measured data is used to calibrate the WinAM 4.3 model "a.1basemodel". The calibrated model is named "b.1basemodel". The calibration steps are in Table 5-30.

**Table 5-30** Calibration for Sunset Valley Elementary School

| Component | AHU Group | Before Calibration | After Calibration |
|---|---|---|---|
| Window percentage | AHU Group 2 | 30% | 20% |
| Constant primary flow | AHU Group 2 | 1 CFM | 2.3 CFM |
| | AHU Group 1 | 1 CFM | 0.9 CFM |
| Hot deck temperature | AHU Group 1 | 95°F | 90°F |

During the calibration process, an error of the measured data was found, one month of gas consumption was lost. The gas consumption data is in Table 5-31:

**Table 5-31** Gas consumption data for Sunset Valley Elementary School

| Start Date | End Date | Measured (CCF) |
|---|---|---|
| 5/30/2007 | 6/29/2007 | 0 |
| 6/30/2007 | 7/28/2007 | 0 |
| 7/29/2007 | 8/30/2007 | 7 |
| 8/31/2007 | 9/27/2007 | 126 |
| 9/28/2007 | 10/30/2007 | 228 |
| 10/31/2007 | 11/29/2007 | 882 |
| 11/30/2007 | 12/30/2007 | |
| 12/31/2007 | 1/29/2008 | 2775 |
| 1/30/2008 | 2/27/2008 | 1901 |
| 2/28/2008 | 3/28/2008 | 1507 |
| 3/29/2008 | 4/28/2008 | 672 |
| 4/29/2008 | 5/29/2008 | 167 |

The way to solve it is to use the data from a similar time period which comes from the baseline model created for this report.

5.5.2.4 Apply CC® measures to the calibrated model

The CC® measures are applied to model “b.1basemodel”.  That new model is named as “b.2basemodel”

## 5.6 DFW International Airport North Business Tower

5.6.1 Background (ESL 2010b)

This project is a four-story and 52,000 $ft^2$ office building. It was built in 1978. This building has a rectangular floor plan which is covered with glass. The area of the second, third and fourth floors of this building is around 15,000 $ft^2$. Three Single Duct Variable Air Volume AHUs (SDVAV AHUs) serve this building. The smallest SDVAV AHU only serves 1,800 $ft^2$ of the first floor. The remaining two SDVAV AHUs serve the remaining area equally. The hot water and chilled water both come from the energy plaza on site.

From the description in the report, all AHUs in this building are SDVAV, and there is no large difference between each AHU. But based on CC® measures applied to this project, three AHU groups need to be created in WinAM 4.3. The only difference between these three models is that the conditioned area for each group is different.

**Table 5-32** General information of DFW International Airport North Business Tower

| Category | Item | Content |
|---|---|---|
| Envelope | U-value for wall | $0.151\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| | U-value for roof | $0.048\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| | U-value for window | $0.75\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| | Interior zone percentage | 70% |
| | Exterior wall and window area | 43568 $ft^2$ |
| | Window percentage | 60% |

**Table 5-32** continued

| Category | Item | Content |
|---|---|---|
| Envelope | Conditioned floor area | 52000 $\mathrm{ft}^2$ |
| Loads and schedule | Nighttime lighting and plug load ratio | 0.2 |
| | Weekday peak load ratio | 1 |
| | Weekend peak load ratio | 0.3 |
| | Weekday operating hours | 7:00 a.m. to 6:00 p.m. |
| | Weekend operating hours | off |
| | Peak weekly lighting usage | 1 $\mathrm{w/ft}^2$ |
| | Peak weekly plug load | 1 $\mathrm{w/ft}^2$ |
| | Peak weekly occupancy | 100 $\mathrm{ft}^2\mathrm{/person}$ |
| Secondary system and schedule | Normal weekday schedule | 6:00 a.m. to 8:00 p.m. |
| | Normal weekend schedule | Off |
| | Special weekday schedule | Off |
| | Special weekend schedule | Off |
| | Maximum primary flow | 1.1 $\mathrm{CFM/ft}^2$ |
| | Minimum primary flow ( occupied) | 0.4 $\mathrm{CFM/ft}^2$ |
| | Minimum primary flow ( unoccupied) | 0 $\mathrm{CFM/ft}^2$ |
| | Minimum outside airflow ( occupied) | 20% |
| | Minimum outside airflow (unoccupied) | 10% |
| | Preheat coil setpoint | 60°F |
| | Cooling coil setpoint | 53°F |
| | Space setpoint | 70°F |
| | Supply fan power | 0.85 $\mathrm{HP/kCFM}$ |
| | Return fan power | 0.4 $\mathrm{HP/kCFM}$ |

### 5.6.2 Modeling process

#### 5.6.2.1 Base model for WinAM 4.3

The DFW International Airport North Business Tower WinAM 4.3 base model "a.1basemodel" is simulated based on the information offered in Section 5.6.1 Background.

#### 5.6.2.2 Apply CC® measures to WinAM 4.3 model

The CC® measures are applied to the model "a.1basemodel". The new model is named "a.2basemodel".

Table 5-33 shows the detailed CC® measures which can be applied to WinAM 4.3.

**Table 5-33 CC®** measures that apply to the information of DFW International Airport North Business Tower

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Cooling coil reset | AHU Group 1, 2 | 53°F | When the OAT is lower than 40°F, the cooling coil temperature is 65°F. When the OAT is higher than 75°F, the hot water coil temperature is 53°F. |
| Return fan | AHU Group 1 | on | off |
| Preheat | All | 60°F | Decrease the preheat coil temperature from 60°F to 40°F for AHU Group 1 and 2. Decrease the preheat coil temperature from 60°F to 50°F for AHU Group 3. |
| Zone temperature | All | 73°F | 71°F |

Table 5-34 lists the CC® measures which cannot be applied to WinAM 4.3.

**Table 5-34** CC® measures that cannot be applied to the simulated WinAM 4.3 model of DFW International Airport North Business Tower

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Static pressure reset | AHU Group 1, 2 | 2 inches of water | When the OAT is lower than 100°F, the static pressure is 1.5 inches of water. When the OAT is higher than 50°F, the static pressure is 0.7 inches of water. |
| Occupied schedule | All | Occupied from 6:00 a.m. to 8:00 p.m. | Based on the schedule, when it is unoccupied, the static pressure will be reduced to minimum and the supply air temperature minimum side will be reduced to 55°Fo |
| Zone temperature reset | All | 73°F | When it is unoccupied, the zone temperature will be reset to 78℉ |
| Hot water supply temperature | | | When the outside air temperature is lower than 30°F, the hot water temperature will be 160°F. When the OAT is higher than 60°F, the supply hot water temperature will be 100°F. |
| Hot water pump | | Enable when the OAT is lower than 70°F. | Hot water pump #1 will be enabled when the OAT is lower than 63℉ wheBoth of the hot water pumps will run when the OAT is lower than 40℉ o |

5.6.2.3 Calibrate WinAM 4.3 model

The baseline model "a.1basemodel" is calibrated based on the measured data. The new model is named "b.1basemodel". The calibration process is listed in Table 5-35.

**Table 5-35** Calibrations applied to the DFW International Airport North Business Tower

| Item | AHU Group | Before Calibration | After Calibration |
|---|---|---|---|
| Maximum primary flow | AHU Group 3 | $1.1\ \mathrm{CFM/ft^2}$ | $2.5\ \mathrm{CFM/ft^2}$ |
| Zone temperature | AHU Group 3 | 70°F | 72°F |
| Cooling coil | All | 53°F | 50℉ |
| Peak plug | AHU Group 1,2 | $1\ \mathrm{w/ft^2}$ | $1.5\ \mathrm{w/ft^2}$ |
| Unoccupied airflow | AHU Group 1,2 | $0\ \mathrm{CFM/ft^2}$ | $0.1\ \mathrm{CFM/ft^2}$ |
| Maximum primary airflow | AHU Group 1,2 | $1.2\ \mathrm{CFM/ft^2}$ | $1.6\ \mathrm{CFM/ft^2}$ |
| Minimum occupied primary flow | All | $0.4\ \mathrm{CFM/ft^2}$ | $0.5\ \mathrm{CFM\ /ft^2}$ |
| Non-HVAC electric | All | 0 kW | 330 kW |

In Table 5-35, there is no non-HVAC electric cost before calibration but 330 kW after calibration. The purpose for non-HVAC electric adjustment is for calibration. After calculating the savings after applying CC® measures to the model, the non-HVAC electric consumption will be reduced to 0 kW again.

5.6.2.4 Apply CC® measures to the calibrated model

Apply CC® measures to "b.1basemodel" and name the new model "b.2basemodel".

**5.7 Blanchfield Army Community Hospital, Fort Campbell, Kentucky**

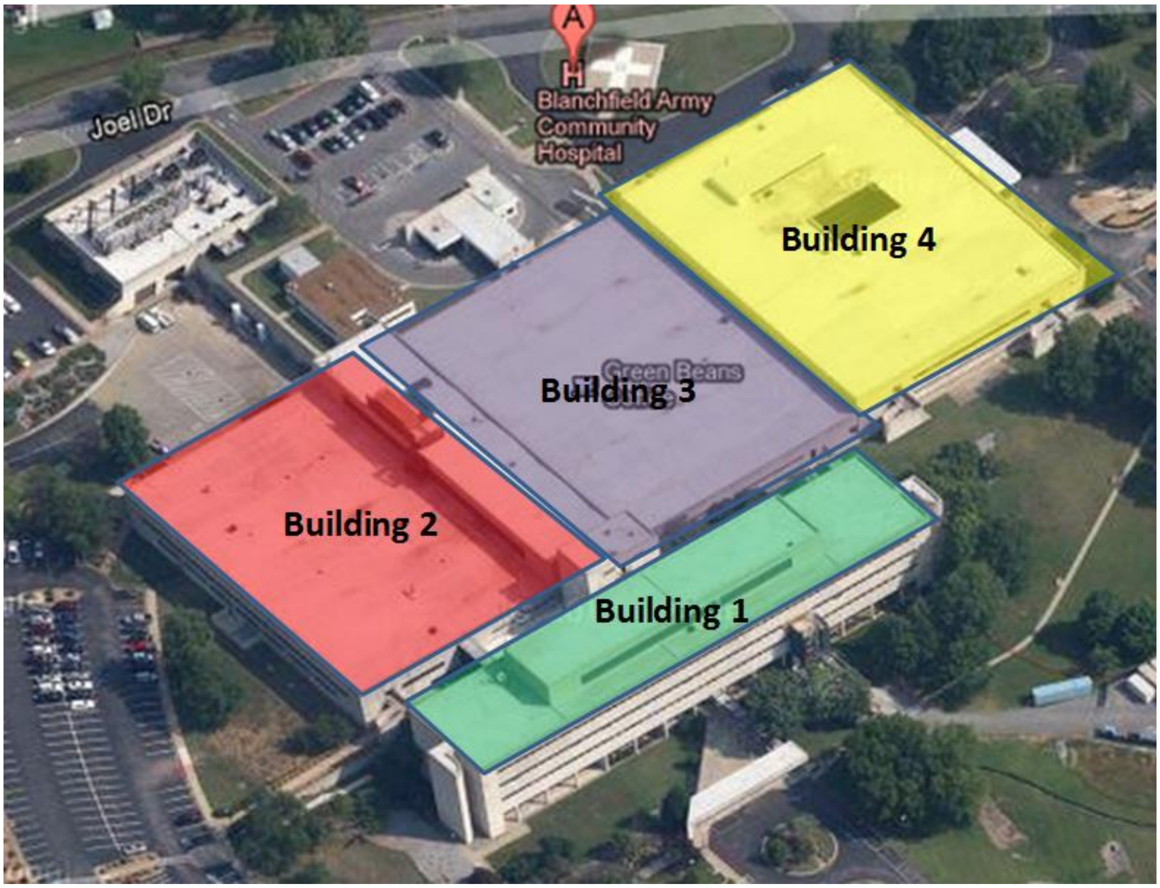



**Figure 5-5** Overhead view of Blanchfield Army Community Hospital (Google Map 2013)

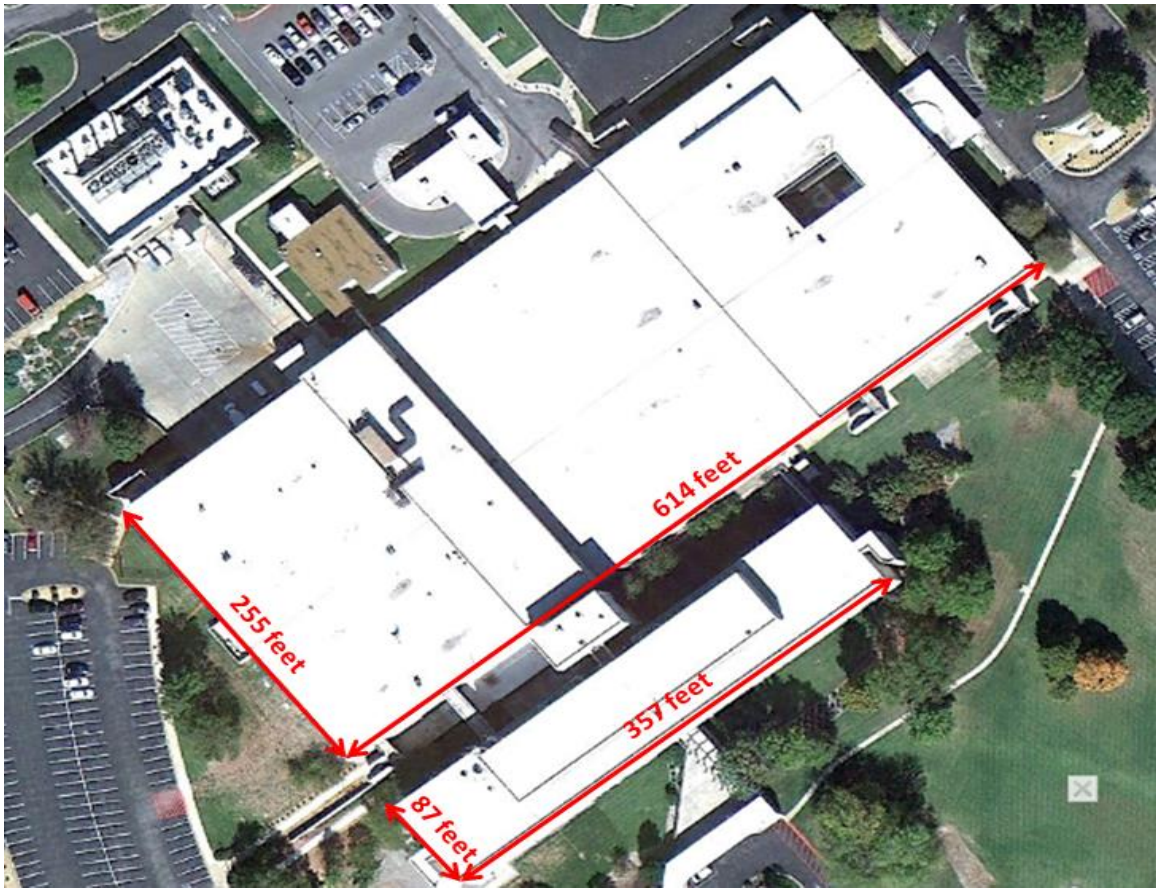


**Figure 5-6** Dimensions of each building in Blanchfield Army Community Hospital (Google Map 2013)

5.7.1 Background (Bes-Tech Inc. and ESL 2009b)

The Blanchfield Army Community Hospital (BACH) is located in Kentucky, Climate Zone 4. Figure 5-5 and Figure 5-6 come from the Google map of that location. This project has 4 buildings in total. The gross area is approximately 440,000 square feet. The dimension of the project has been marked in Figure 5-6. CC® measures have been applied to this hospital beginning in April 2006 and finished in December 2006. From

February, 2009 to July, 2009 the enhanced CC® measures have been applied to this project.

There are 18 AHUs in this project. They include 5 Single Duct Variable Air Volume AHUs, 2 Single Duct Constant Air Volume AHUs, 4 Dual Duct Constant Air Volume AHUs, 4 single zone unit AHUs, 2 multi-zone constant air volume AHUs and one roof top AHU. All of the AHUs run 24/7 except the AHU that serves the kitchen. To simplify the modeling process, this unit will be treated as if it runs 24/7 as well.

This project has the plant on site. There are three chillers in total; two are 630 ton and the remaining one is 800 ton. Each chiller has one 75 horsepower chilled water pump. The cooling tower has six cells; each cell has a 25 horsepower fan. Two 60 horsepower and one 50 horsepower pumps have been applied to serve this cooling tower. There are three steam boilers on site to assist the hot water supply.

The envelope information for BACH is in Table 5-36.

**Table 5-36** Envelope information of BACH

| Item | Content |
|---|---|
| U-value for wall (mass) | $0.104\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| U-value for roof | $0.048\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| U-value for window | $0.55\ \mathrm{Btu/(hr * ft^2 * °F)}$ |
| Interior zone percentage | 80% |
| Exterior wall and window area | $102908\ \mathrm{ft^2}$ |
| Window percentage | 25% |
| Conditioned floor area | $440000\ \mathrm{ft^2}$ |

The information on U-values is based on the WinAM 4.3 help manual: how to use WinAM to calculate savings from energy conservation measures (ESL 2013a).

Since the information offered by the CC® report is not very suitable for WinAM 4.3, almost 40% of the inputs are based on assumption.

18 AHUs have been divided into 11 AHU groups. They are separated based on the AHU system, the supply air temperature, whether they use an economizer and the cooling coil temperature setpoint. Table 5-37 is the information for AHU Group 1.

**Table 5-37** AHU Group 1: SDVAV with the economizer of BACH

| Category | Item | Data |
|---|---|---|
| Loads and schedule | Nighttime lighting and plug load ratio | 0.3 |
| | Weekday peak load ratio | 1 |
| | Weekend peak load ratio | 0.3 |
| | Lighting and plug load weekday operating hours | 4:00 a.m. to 7:00 p.m. |
| | Lighting and plug load weekend operating hours | 4:00 a.m. to 7:00 p.m. |
| | Peak weekly lighting usage | $1.2\ \mathrm{w/ft^2}$ |
| | Peak weekly plug load | $2.2\ \mathrm{w/ft^2}$ |
| | Peak weekly occupancy | $100\ \mathrm{ft^2/person}$ |
| Secondary system and schedule | AHU normal weekday schedule | 24/7 |
| | AHU normal weekend schedule | 24/7 |
| | Space temperature setpoint | 72˚F |
| | Minimum primary flow | $0.3\ \mathrm{CFM/ft^2}$ |
| | Maximum primary flow | $1\ \mathrm{CFM/ft^2}$ |
| | Minimum outside airflow | 30% |

**Table 5-37** continued

| Category | Item | Data |
|---|---|---|
| Secondary system and schedule | Economizer: temp | 38˚F to 58˚F |
| | Cooling coil setpoint | When the OAT is 55˚F to 40˚F, the cooling coil temperature is 55˚F to 57˚F. |
| | Supply fan power | 0.85 HP/kCFM |

Table 5-38 provides the information for AHU Group 2. The AHUs in this group are similar to the AHUs in Group 1, except for the cooling coil temperature setpoint.

**Table 5-38** AHU Group 2: SDVAV with the economizer of BACH

| Item | Data |
|---|---|
| Cooling coil setpoint | When the OAT is 55˚F to 40˚F, the cooling coil temperature is 61˚F to 65˚F. |

Table 5-39 shows the information of AHU Group 3. AHU Group 3 is similar to AHU Group 1, except for the cooling coil setpoint temperature and the fact that this group does not have the economizer.

**Table 5-39** AHU Group 3: SDVAV without the economizer of BACH

| Item | Data |
|---|---|
| Cooling coil temperature setpoint | 56˚F |

Table 5-40 is the information about AHU Group 4. AHU Group 4 is similar to AHU Group 1, except for the cooling coil temperature setpoint.

**Table 5-40** AHU Group 4: SCVAV with the economizer of BACH

| Item | Data |
|---|---|
| Cooling coil temperature setpoint | When the OAT is 55˚F to 40˚F, the cooling coil temperature is 61˚F to 65˚F. |

Table 5-41 is the information about AHU Group 5. AHU Group 5 is similar to AHU Group 1, except for the cooling coil temperature setpoint.

**Table 5-41** AHU Group 5: SDCAV without the economizer of BACH

| Item | Data |
|---|---|
| Cooling coil setpoint | When the OAT is 50˚F to 60˚F, the cooling coil temperature is 56˚F to 50˚F |

Table 5-42 gives the information about AHU Group 6. AHU Group 6 is similar to AHU Group 1, except for the temperature setpoint for the hot deck, the temperature setpoint for the cold deck, and the economizer range.

**Table 5-42** AHU Group 6: DDCAV with the economizer of BACH

| Item | Data |
|---|---|
| Cold deck | 47˚F |

**Table 5-42** continued

| Item | Data |
|---|---|
| Hot deck | 87˚F |
| Economizer | 37˚F to 55˚F |

Table 5-43 gives the information about AHU Group 7. AHU Group 7 is similar to AHU Group 1, except for the temperature setpoints for the hot deck and the cold deck.

**Table 5-43** AHU Group 7: DDCAV without the economizer of BACH

| Item | Data |
|---|---|
| Cold deck | When the OAT is 50˚F to 40˚F, the cold deck temperature is 49˚F to 53˚F. |
| Hot deck | When the OAT is 50˚F to 40˚F, the cold deck temperature is 75˚F to 85˚F. |

AHU Group 8: Single zone system without the economizer

From the CC® report, the cooling coil temperatures are different from each other for the 3 identical single zone units. To simplify the modeling process, we use one temperature for three cooling coils in WinAM 4.3.

AHU Group 9: Single zone system without the economizer

The only difference between AHU Group 9 and AHU Group 8 is that AHU Group 9 uses 100% outside air.

AHU Group 10: Multi-zone constant air volume system with the economizer.

There is no multi-zone system in WinAM 4.3.  This is because this system is no longer popular in commercial buildings, and WinAM 4.3 focuses on commercial buildings. The DDCAV system with the economizer will be used to replace the multi-zone constant air volume system in analysis performed using WinAM 4.3.

Table 5-44 offers the information about AHU Group 10. The differences between AHU Group 10 and AHU Group 1 are: HVAC system type, the economizer temperature range, and the temperature setpoints for the hot deck and the cold deck.  Table 5-45 offers the information of AHU Group 11.

**Table 5-44** AHU Group 10: Multi-zone constant air volume system with the economizer of BACH

| Item | Data |
|---|---|
| Cold deck | 57˚F |
| Hot deck | When the OAT is 45˚F to 65˚F, the cold deck temperature is 51˚F to 65˚F. |
| Economizer | 38˚F to 58˚F |

**Table 5-45** AHU Group 11: Multi-zone constant air volume system without the economizer of BACH

| Item | Data |
|---|---|
| Cold deck | 57˚F |
| Hot deck | When the OAT is 50˚F to 40˚F, the cold deck temperature is 83˚F to 85˚F. |

In the CC® report for this project, there is no clear information about the area assigned to the different AHUs, so the assumption of assigning each AHU an equal area has been made. We make the same assumption about the assignment of the areas of the roof, the windows and the walls.

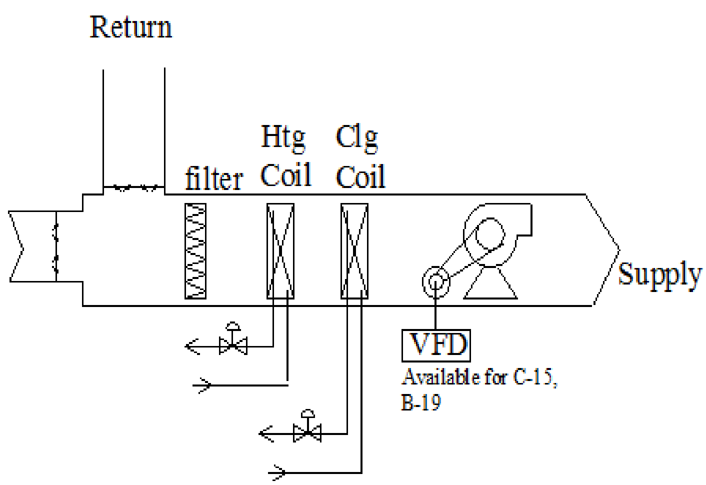



**Figure 5-7** SDVAV system for real CC® project (Bes-Tech Inc., and ESL. 2009a)

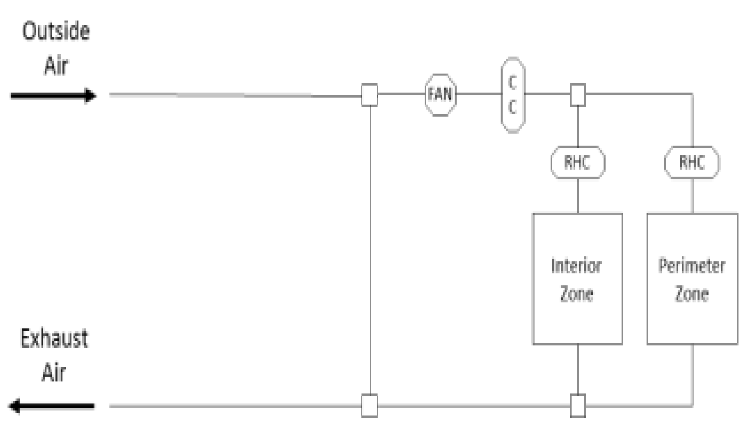



**Figure 5-8** SDVAV system in WinAM 4.3

Figure 5-7 is the SDVAV system structure from the CC® report for this project, while Figure 5-8 is the SDVAV system structure from WinAM 4.3. Comparing these two figures, the hot water coil in the real CC® project is before the cooling coil; while in WinAM 4.3 only the reheat is used. The position of the fan in the real CC® project is after the cooling coil, while in WinAM 4.3 the fan is before the cooling coil.

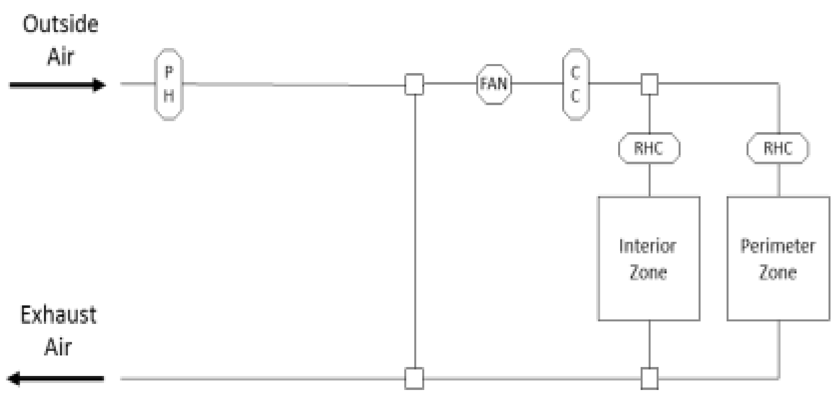



**Figure 5-9** SDVAV system in WinAM 4.3 with preheat

Although WinAM 4.3 has the preheat option, see Figure 5-9, it is preheating for the OAT not for heating the mixed air. In the real project, the preheat coil is for heating the mixed air, as shown in Figure 5-7.

5.7.2 Modeling process

5.7.2.1 Base model for WinAM 4.3

The Blanchfield Army Community Hospital base model is simulated based on the data documented earlier. That model is named “a.1basemodel”. There is no suitable weather station that can be found in Kentucky, consequently a weather station in Tennessee that is within 100 miles of the Blanchfield Army Community Hospital has been used.

5.7.2.2 Apply CC® measures to WinAM 4.3 model

The CC® measures are applied to the model "a.1basemodel" without calibrating it. This model is named "a.2basemodel".

Table 5-46 lists the CC® measures which can be applied to the WinAM 4.3 model.

**Table 5-46** CC® measures that apply to BACH

| AHU Group | Item | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Group 1 SDVAV | Cold deck | When the OAT is 55°F to 40°F, the temperature setpoint is 55°F to 57°F. | When the OAT is 40°F to 55°F, the cold deck temperature is 61.5°F to 56.5°F. |
| | Economizer | 38°F to 58°F | Enable the economizer when the OAT is under the range from 38°F to 65°F. |
| Group 2 SDVAV | Cold deck | When the OAT is from 55°F to 40°F, the temperature setpoint is from 61°F to 65°F. | When the OAT is from 40°F to 55°F, the cold deck temperature is from 61.5°F to 56.5°F. |
| | Economizer | From 38°F to 58°F | Enable the economizer when the OAT is under the range from 38°F to 65°F. |
| Group 3 SDVAV | Cold deck | 56°F | When the OAT is from 40°F to 55°F, the cold deck temperature is from 61.5°F to 56.5°F. |
| | Economizer | Without the economizer | Enable the economizer when the OAT is under the range from 38°F to 65°F. |

**Table 5-46** continued

| AHU Group | Item | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Group 4 SDCAV | Cold deck | 59°F | When the OAT is from 40°F to 55°F, the cold deck temperature is from 61.5°F to 56.5°F. |
| | Economizer | From 38°F to 58°F | Enable the economizer when the OAT is under the range from 38°F to 65°F. |
| Group 5 SDCAV | Cold deck | When the OAT is from 50°F to 60°F, the temperature setpoint is from 56°F to 50°F. | When the OAT is 40°F to 55°F, the cold deck temperature is 61.5°F to 56.5°F. |
| | Economizer | None | Enable the economizer when the OAT is in the temperature range from 38°F to 65°F. |
| Group 6 DDCAV | Hot deck | 87°F | When the OAT is from 40°F to 60°F, the hot deck temperature setpoint is from 83.5°F to 73.5°F. |
| | Cold deck | 47°F | When the OAT is 50°F to 60°F, the cold deck temperature is from 59.5°F to 55.6°F. |
| | Economizer | From 37°F to 55°F | Enable the economizer when the OAT is in the temperature range from 38°F to 65°F. |
| Group 7 DDCAV | Hot deck | When the OAT is from 50°F to 40°F, the hot deck temperature setpoint is from 75°F to 85°F. | When the OAT is from 40°F to 60°F, the hot deck temperature setpoint is from 83.5°F to 73.5°F. |
| | Cold deck | When the OAT is from 50°F to 40°F, the temperature septoint is from 49°F to 53°F. | When the OAT is from 50°F to 60°F, the cold deck temperature is from 59.5°F to 55.6°F. |
| | Economizer | None | Enable the economizer when the OAT is under the range from 38°F to 65°F. |

**Table 5-46** continued

| AHU Group | Item | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Group 8 SZ | Economizer | None | Enable the economizer when the OAT is under the range from 38°F to 65°F. |
| Group 9 SZ | Economizer | None | Enable the economizer when the OAT is under the range from 38°F to 65°F. |
| Group 10 MZ | Cold deck | 57°F | When the OAT is from 50°F to 60°F, the temperature setpoint is from 59.5°F to 55.6°F. |
| | Hot deck | When the OAT is from 45°F to 65°F, the temperature setpoint is from 81°F to 65°F. | When the OAT is from 40°F to 60°F, the hot deck temperature setpoint is from 78.5°F to 70°F. |
| | Economizer | From 38°F to 58°F | Enable the economizer when the OAT is under the temperature range from 38°F to 65°F. |
| Group 11 MZ | Cold deck | 57°F | When the OAT is 50°F to 60°F, the cold deck temperature is 59.5°F to 55.6°F. |
| | Hot deck | When the OAT is from 50°F to 40°F, the temperature setpoint is from 83°F to 85°F. | When the OAT is 40°F to 60°F, the hot deck temperature setpoint is 78.5°F to 70°F. |
| | Economizer | None | Enable the economizer when the OAT is under the temperature range from 38°F to 65°F. |

The coil temperatures applied to WinAM 4.3 have been edited based on the data in the CC® report. The real project uses both the unoccupied model and the occupied model for the coil temperature reset, and WinAM 4.3 doesn't have this option yet.  The method used to solve this problem is to calculate the compromised temperature based on the ratio of the occupied time and the unoccupied time.

Following is an example of the calculation of this temperature (Figure 5-10).

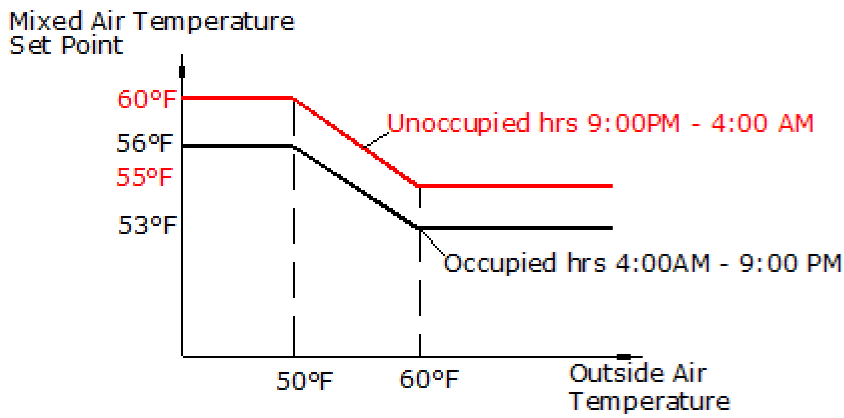



**Figure 5-10** Mixed air temperature setpoint (Bes-Tech Inc., and ESL. 2009a)

Figure 5-10 shows the unoccupied hours are from 9:00 p.m. to 4:00 a.m. which total 7 hours, so the remaining 17 hours are the occupied time.

The compromised temperature for cold deck upper limit will be:

$$60°\mathrm{F} * \left(\frac{7}{24}\right) + 56°\mathrm{F}\left(\frac{17}{24}\right) = 57.16°\mathrm{F}$$

The compromised temperature for cold deck lower limit is:

$$55°\mathrm{F} * \left(\frac{7}{24}\right) + 53°\mathrm{F}\left(\frac{17}{24}\right) = 53.58°\mathrm{F}$$

The CC® measures that cannot be applied to the WinAM 4.3 model are listed in Table 5-47:

**Table 5-47 CC® measures that cannot be applied to the WinAM 4.3 model**

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Zone temperature occupied and unoccupied mode | All | Based on manual adjustment | Occupied hours from 4:00 a.m. to 7:00 p.m.<br>Unoccupied hours are from 7:00 p.m. to 4:00 a.m. During unoccupied time, the heating temperature is 60°F and the cooling temperature is 85°F. |
| Economizer | All | Some of the AHUs have the economizer | Economizers will be enabled when the OAT is lower than 65°F, and the mechanical cooling will be shut off when the OAT is below 52°F. |
| Relative humidity ratio reset | Group 2 | Doesn't mention | When the OAT is 30°F, the relative humidity ratio is 40%. When the OAT is 50°F, the relative humidity ratio is 45%. |
| Reset cold deck and hot deck temperature | Groups 2,3,4 | The cold deck and the hot deck temperature do not have the relationship between the occupied mode and the unoccupied mode. | The cold deck and the hot deck temperature setpoint are set not only based on the OAT but also based on the occupied mode and the unoccupied mode. |
| Reset mixed air temperature | Group 2 | Doesn't mention | Reset the mixed air temperature setpoint based on the OAT. |

**Table 5-47** continued

| Item | AHU Group | Before CC® Measures | After CC® Measures |
|---|---|---|---|
| Duct static pressure | Group 5 | Doesn't mention | Maintain the duct static pressure at its setpoint and reset the duct pressure based on the fan speed. |
| Supply temperature reset | Group 6 | Manually adjusted | Reset the supply air temperature based on the OAT and the room temperature. |
| Condensed water temperature reset | | Doesn't mention | When the OAT is 70°F, the supply condensed water temperature is 85°F. When the OAT is 75°F, the supply condensed water temperature is 95°F. |
| Boiler | | Doesn't mention | 1. Steam pressure has been reduced, 2. heat exchanger pressure has been reduced, and 3. supply hot water temperature has been reset. |

5.7.2.3 Calibrate WinAM 4.3 model

The calibration steps for this project are in Table 5-48.

**Table 5-48** Calibrations for BACH

| AHU Group | Item | Before Calibration | After Calibration |
|---|---|---|---|
| All | Lighting | 1.2 Watts/ft2 | 0.85 Watts/ft2 |
| | Plug | 2.2 Watts/ft2 | 1.55 Watts/ft2 |
| AHU 1 | Minimum airflow | 0.3 CFM | 0.4 CFM |
| | OA% | 100% | 70% |

**Table 5-48** continued

| AHU Group | Item | Before Calibration | After Calibration |
|---|---|---|---|
| AHU 2 | Maximum airflow | 1 CFM | 1.4 CFM |
| AHU 3 | Minimum airflow | 0.3 CFM | 0.4 CFM |
| AHU 4 | Constant primary airflow | 1 CFM | 1.65 CFM |
| | OA% | 100% | 70% |
| AHU 5 | Constant primary airflow | 1 CFM | 1.55 CFM |
| AHU 6 | Constant primary airflow | 1 CFM | 1.45 CFM |
| | OA% | 100% | 70% |
| AHU 7 | Constant primary airflow | 1 CFM | 1.45 CFM |
| AHU 8 | Constant primary airflow | 1 CFM | 1.45 CFM |
| AHU 9 | Constant primary airflow | 1 CFM | 1.45 CFM |
| AHU 10 | Constant primary airflow | 1 CFM | 1.65 CFM |
| | OA% | 100% | 70% |
| AHU 11 | Constant primary airflow | 1 CFM | 1.65 CFM |
| Plant | Electric cooling system efficiency | 1 kw/ton | 0.9 kw/ton |
| | Gas heating system efficiency | 80% | 55% |

5.7.2.4 Apply CC® measures to the calibrated model

We apply the same CC® measures discussed in Section 5.7.2.2 to the calibrated WinAM 4.3 model "b.1basemodel". The new model is named "b.2basemodel".

# 6. RESULTS

## 6.1 Introduction

This section focuses on the analysis of the results generated from the input parameter sensitivity analysis (Section 4) and the savings prediction experiment (Section 5).

The method to detect the sensitivity for the selected 14 parameters is to calculate the yearly influence coefficient (IC) for each input based on monthly data. We then compare 14 IC values with each other within the same AHU system.

The methods applied to analyze the savings prediction reliability results are the following. The savings were calculated after applying CC® measures to the projects with and without calibration. The statistical methods NMBE and CV (RMSE) will be used for evaluating whether the model has been well-calibrated or not. According to ASHRAE Guideline 14, the model is considered well-calibrated if the NMBE is within $\pm 5\%$ and the CV(RMSE) is within $\pm 15\%$ when the model is calibrated with the monthly measured data. This allows us to figure out whether the well-calibrated model has the better predicted savings than the calibrated model.

## 6.2 Results for sensitivity analysis

After analyzing the sensitivity of each parameter in Section 4, this section will focus on how the parameters affect the yearly energy consumptions. A yearly energy consumption IC value has been calculated for each input parameter. Figure 6-1 through

Figure 6-3 show the input parameter's effect on electric, chilled water and hot water consumption for the system with the economizer.

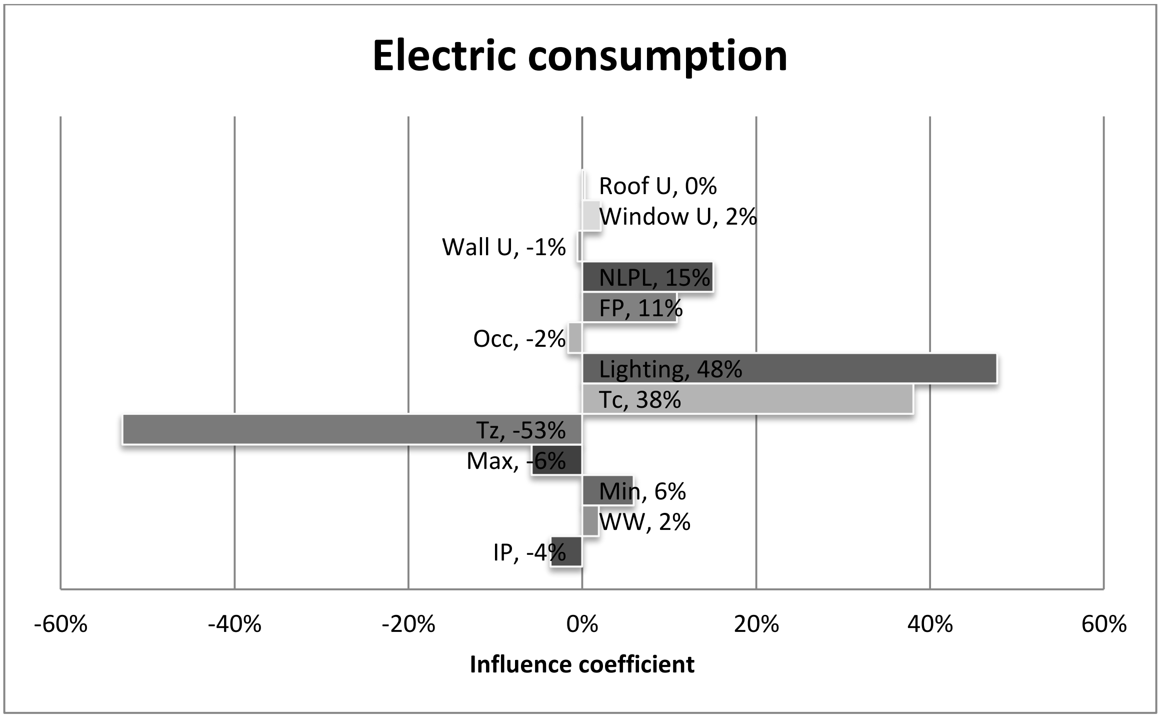



**Figure 6-1** IC for electric consumption with the economizer

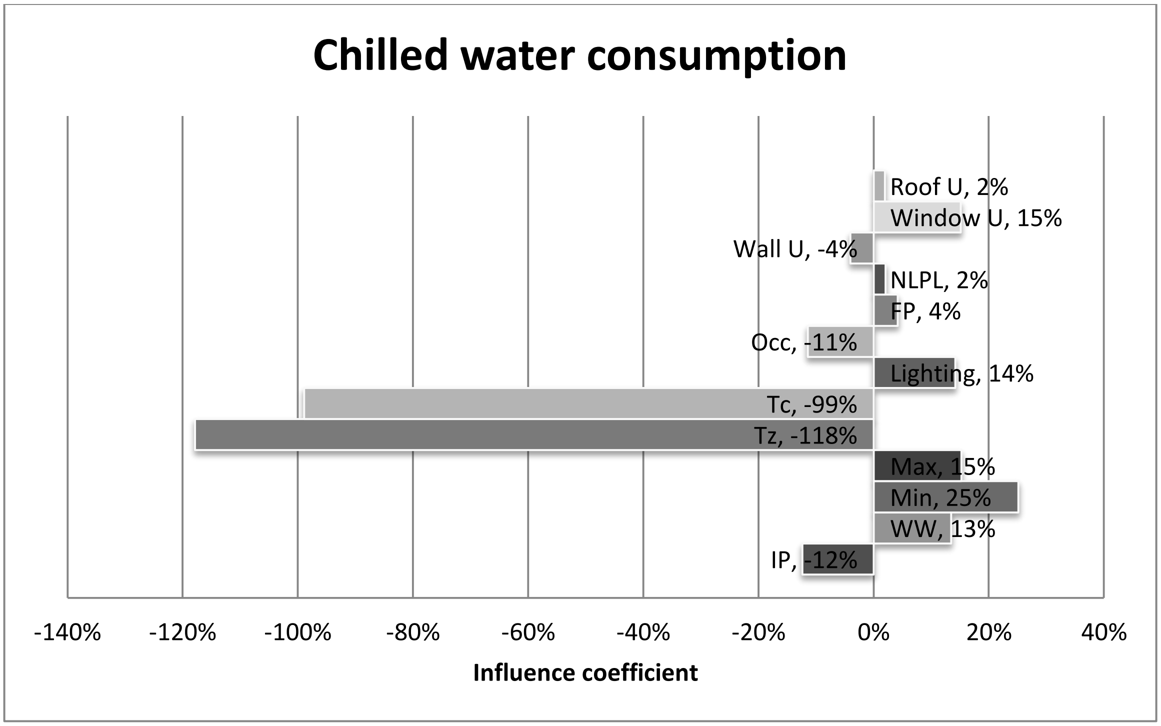



**Figure 6-2** IC for chilled water consumption with the economizer

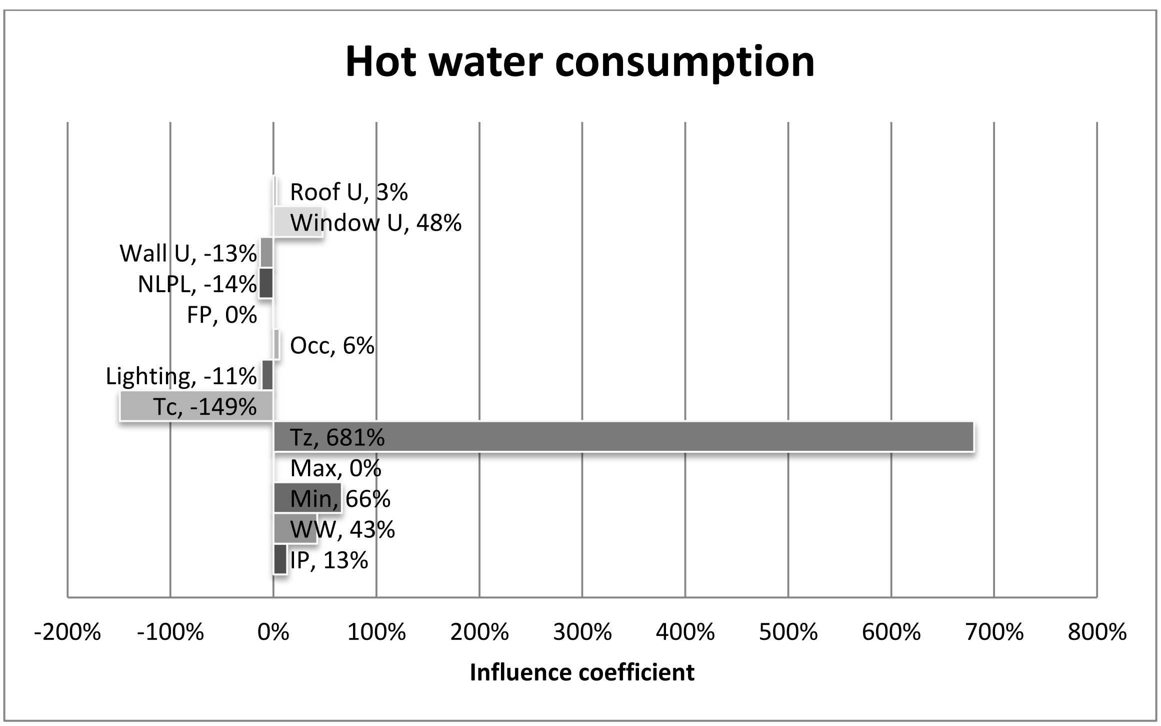



**Figure 6-3** IC for hot water consumption with the economizer

Figure 6-4 through Figure 6-6 show the input parameter's effect on electric, chilled water and hot water consumption for the system without the economizer.

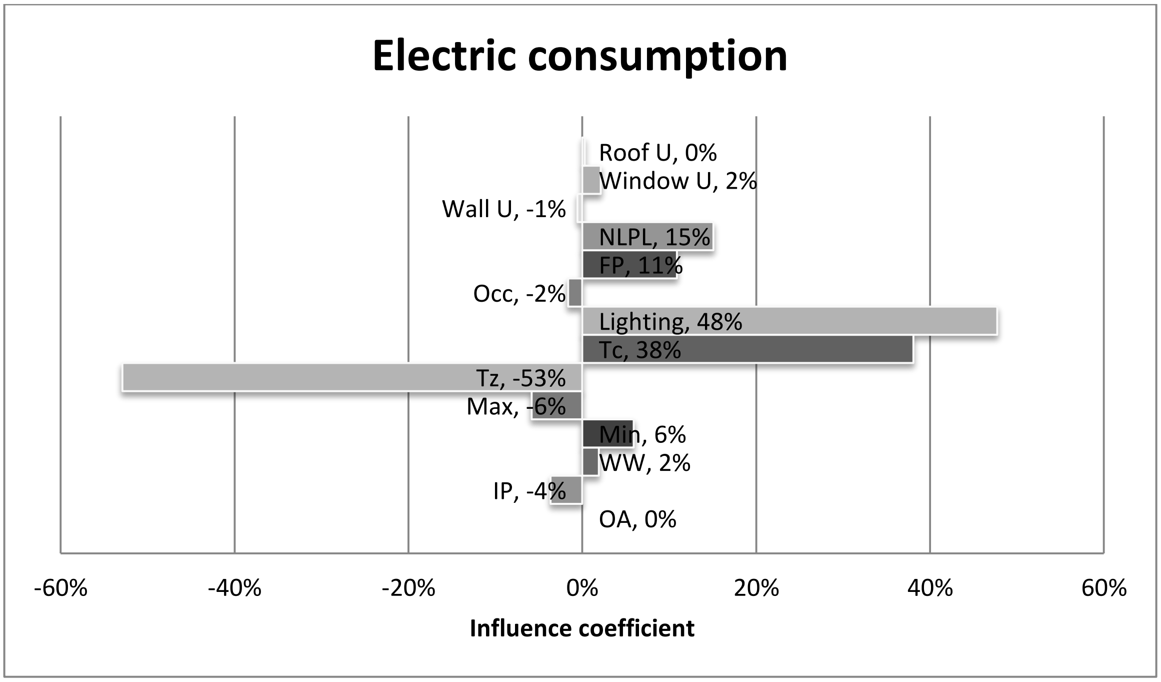



**Figure 6-4** IC for electric consumption without the economizer

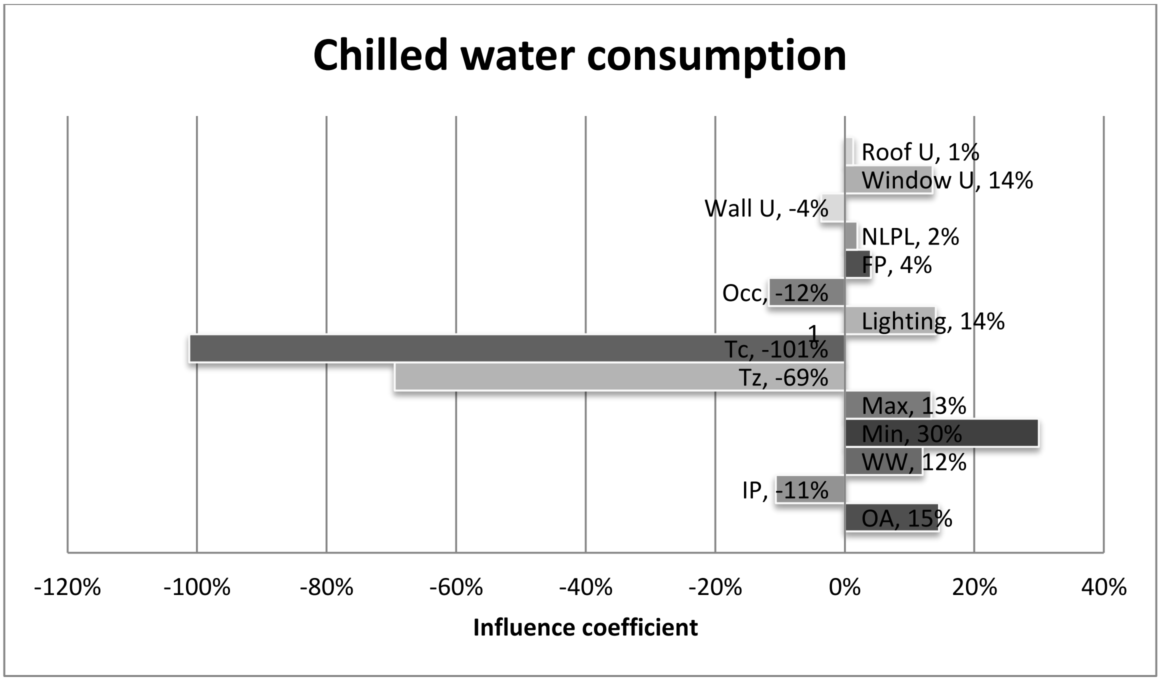



**Figure 6-5** IC for chilled water consumption without the economizer

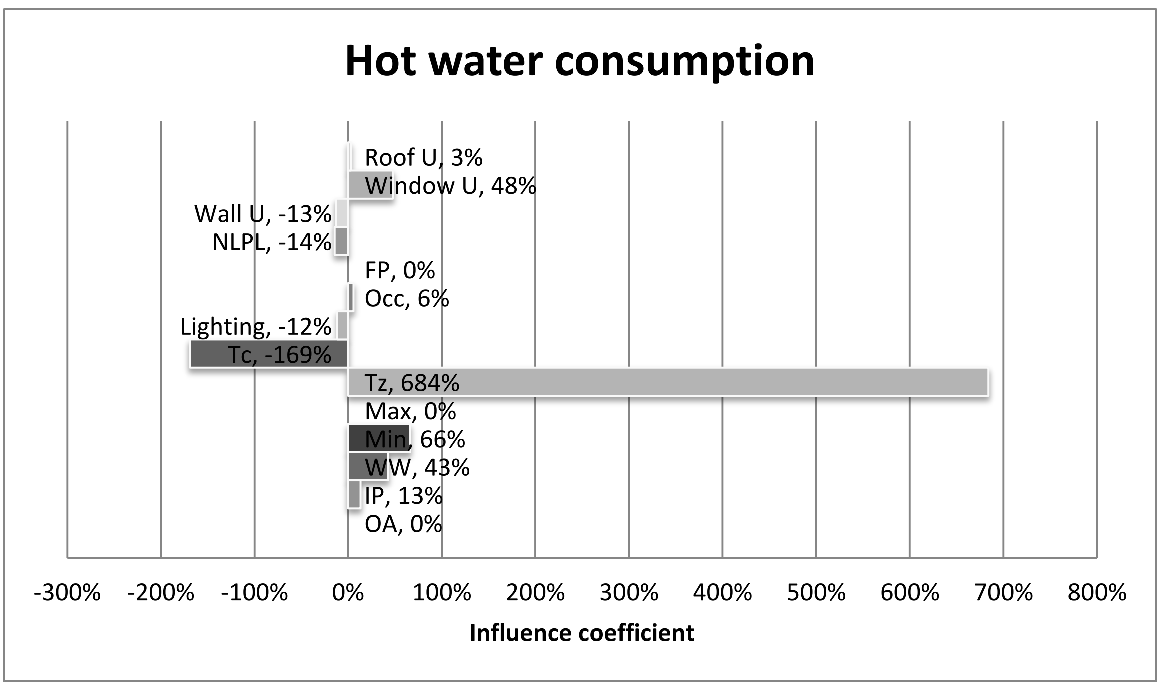



**Figure 6-6** IC for hot water consumption without the economizer

**Table 6-1** Summary of IC for each parameter's sensitivity to different energy recourses in the SDVAV system with the economizer

| Rank No. | Electric | | Chilled water | | Hot water | |
|---|---|---|---|---|---|---|
| 1 | -53%* | Tz | -118%* | Tz | 681%* | Tz |
| 2 | 48% | Lighting | -99%* | Tc | 149%* | Tc |
| 3 | 38%* | Tc | 25% | Min | 66% | Min |
| 4 | 15% | NLPL | 20% | OA | 48% | Window U |
| 5 | 11% | FP | 15% | Max | 43% | WW |
| 6 | 6% | Max | 15% | Window U | 14% | NLPL |
| 7 | -6% | Min | 15% | Lighting | 13% | IP |
| 8 | -4% | IP | 13% | WW | 13% | Wall U |
| 9 | 2% | WW | -12% | IP | 11% | Lighting |
| 10 | 2% | Window U | -11% | Occ | 6% | Occ |
| 11 | -2% | Occ | 4% | FP | 3% | Roof U |
| 12 | -1% | Wall U | -4% | Wall U | 0% | Max |
| 13 | 0% | Roof U | 2% | NLPL | 0% | FP |
| 14 | 0% | OA | 2% | Roof U | 0% | OA |

Table 6-1 provides a summary for ranking the sensitivity of analyzed inputs for the SDVAV system with the economizer. Table 6-2 shows the yearly EPs for each parameter under electric consumption, chilled water consumption and hot water consumption. Column one in Table 6-2 is the same rank number in Table 6-1. In this way, Table 6-2 gives the information for the average energy consumption difference between the adjusted models and the baseline model. The results for Tz and Tc have an "*" in Table 6-1 to Table 6-4 because the average results are not obtained from inputs with the full $\pm$ 30% range. Engineers can decide which input parameter they will spend more time for the accrete prediction result based on Table 6-1 and Table 6-2 for the SDVAV system with the economizer.

**Table 6-2** Summary of absolute EPs for each parameter compare with baseline model to different energy recourses in SDVAV system with the economizer

| IC value rank No. | Electric consumption | | Chilled water consumption | | Hot water consumption | |
|---|---|---|---|---|---|---|
| 1 | 6%* | Tz | 14%* | Tz | 67%* | Tz |
| 2 | 11% | Lighting | 21%* | Tc | 27%* | Tc |
| 3 | 7%* | Tc | 5% | Min | 15% | Min |
| 4 | 3% | NLPL | 4% | OA | 11% | Window U |
| 5 | 2% | FP | 4% | Max | 9% | WW |
| 6 | 1% | Max | 3% | Window U | 3% | NLPL |
| 7 | 1% | Min | 3% | WW | 3% | IP |
| 8 | 1% | IP | 1% | IP | 3% | Wall U |
| 9 | 0% | WW | 3% | OCC | 2% | Lighting |
| 10 | 0% | Window U | 3% | Lighting | 1% | Occ |
| 11 | 0% | Occ | 1% | FP | 1% | Roof U |
| 12 | 0% | Wall U | 1% | Wall U | 0% | Max |
| 13 | 0% | Roof U | 0% | NLPL | 0% | FP |
| 14 | 0% | OA | 0% | Roof U | 0% | OA |

**Table 6-3** Summary of IC for each parameter's sensitivity to different energy recourses in SDVAV system without the economizer

| Rank No. | Electric consumption | | Chilled water consumption | | Hot water consumption | |
|---|---|---|---|---|---|---|
| 1 | -53%* | Tz | -101%* | Tc | 684%* | Tz |
| 2 | 48% | Lighting | -69%* | Tz | -169%* | Tc |
| 3 | 38%* | Tc | 30% | Min | 66% | Min |
| 4 | 15% | NLPL | 15% | OA | 48% | Window U |
| 5 | 11% | FP | 14% | Lighting | 43% | WW |
| 6 | 6% | Min | 14% | Window U | -14% | NLPL |

**Table 6-3** continued

| Rank No. | Electric consumption | | Chilled water consumption | | Hot water consumption | |
|---|---|---|---|---|---|---|
| 7 | -6% | Max | 13% | Max | 13% | IP |
| 8 | -4% | IP | 12% | WW | -13% | Wall U |
| 9 | 2% | Window U | -12% | Occ | -12% | Lighting |
| 10 | 2% | WW | -11% | IP | 6% | Occ |
| 11 | -2% | Occ | 4% | FP | 3% | Roof U |
| 12 | -1% | Wall U | -4% | Wall U | 0% | OA |
| 13 | 0% | Roof U | 2% | NLPL | 0% | Max |
| 14 | 0% | OA | 1% | Roof U | 0% | FP |

Table 6-1 and Table 6-3 provide IC summaries for both the SDVAV system with the economizer and the system without the economizer. The highly sensitive parameters for yearly electric and hot water consumption are the same.

**Table 6-4** Summary of absolute EPs for each parameter compared with the baseline model to different energy recourses in SDVAV system without the economizer

| IC value rank No. | Electric consumption | | Chilled water consumption | | Hot water consumption | |
|---|---|---|---|---|---|---|
| 1 | 6%* | Tz | 19%* | Tc* | 97%* | Tz* |
| 2 | 10% | Lighting | 7%* | Tz* | 30%* | Tc* |
| 3 | 8%* | Tc | 6% | Min | 13% | Min |
| 4 | 3% | NLPL | 3% | OA | 10% | Window U |
| 5 | 2% | FP | 3% | Lighting | 9% | WW |
| 6 | 1% | Min | 0% | Window U | 3% | NLPL |

**Table 6-4** continued

| IC value rank No. | Electric consumption | | Chilled water consumption | | Hot water consumption | |
|---|---|---|---|---|---|---|
| 7 | 1% | Max | 3% | Max | 3% | IP |
| 8 | 1% | IP | 3% | WW | 3% | Wall U |
| 9 | 0% | Window U | 3% | Occ | 2% | Lighting |
| 10 | 0% | WW | 1% | IP | 1% | Occ |
| 11 | 0% | Occ | 1% | FP | 1% | Roof U |
| 12 | 0% | Wall U | 1% | Wall U | 0% | OA |
| 13 | 0% | Roof U | 0% | NLPL | 0% | Max |
| 14 | 0% | OA | 0% | Roof U | 0% | FP |

For each parameter, Table 6-4 provides a summary of yearly EPs for each parameter under electric consumption, chilled water consumption and hot water consumption. Like Table 6-2, it produces the EPs by adjusting the inputs for the SDVAV system without the economizer. The engineers can decide the error range they can accept for any energy recourse based on Table 6-4 and the sensitivity of each parameter in Table 6-3 to choose the best strategy to decide the inputs. This strategy will make the process of measuring each input more efficient.

**6.3 Reliability of savings predictions**

Table 6-5 shows the total dollar savings percentage for each project. It includes the savings obtained from the model without calibration, the model with calibration and the real savings from CC® reports. The predicted savings here are not based on applying the full CC® measures to the WinAM 4.3 models, see Appendix B. The last two columns in the table give the EPs between the measured savings and the simulated savings without and with calibration.  Based on companions of the last two columns, the results from the simulated model with calibration is closer to the measured savings, except for the Sunset Valley Elementary School, the Blanchfield Army Community Hospital and the Austin City Hall models.

The internal cooling and heating load calculated by the inputs generated from the CC® report for the Sunset Valley Elementary School base model are over WinAM 4.3's limitation.  This causes an error in WinAM 4.3.  Under this condition, the inputs are adjusted to run WinAM 4.3.  This adjustment made this model a WinAM 4.3 uncalibrated model.  The reason the predicted total energy savings percentage result obtained from the model with calibration is not as good as that obtained from the model without calibration for Blanchfield Army Community Hospital needs further research.  The bottom line of Table 6-5 denotes that the predicted savings percentage from the calibrated model is closer to the real savings percentage.

**Table 6-5** Dollar savings for each project

| Dollar Savings | | | | | | |
|---|---|---|---|---|---|---|
| No. | Project Name | Predicted savings | | Real Savings | Deviation | |
| | | **Without** Calibration | **With** Calibration | | **Without** Calibration – Real Savings | **With** Calibration – Real Savings |
| 1 | Austin City Hall | 10% | 22% | 17% | -7% | 5% |
| 2 | Dallas/Fort Worth International Airport Terminal D | 4% | 13% | 17% | -13% | -4% |
| 3 | DFW International Airport Rent-A-Car Center | 8% | 9% | 18% | -10% | -9% |
| 4 | DFW Terminal E | 20% | 17% | 9% | 12% | 9% |
| 5 | Sunset Valley Elementary School | 30% | 31% | 21% | 9% | 10% |
| 6 | DFW International Airport North Business Tower | 5% | 15% | 13% | -8% | 2% |
| 7 | Blanchfield Army Community Hospital | 10% | 11% | 9% | 1% | 2% |

Figure 6-7 and Figure 6-8 are the charts of the difference between the calculated savings from the simulated models and the calculated savings from the real models. The corresponding data are given in Table 6-5.

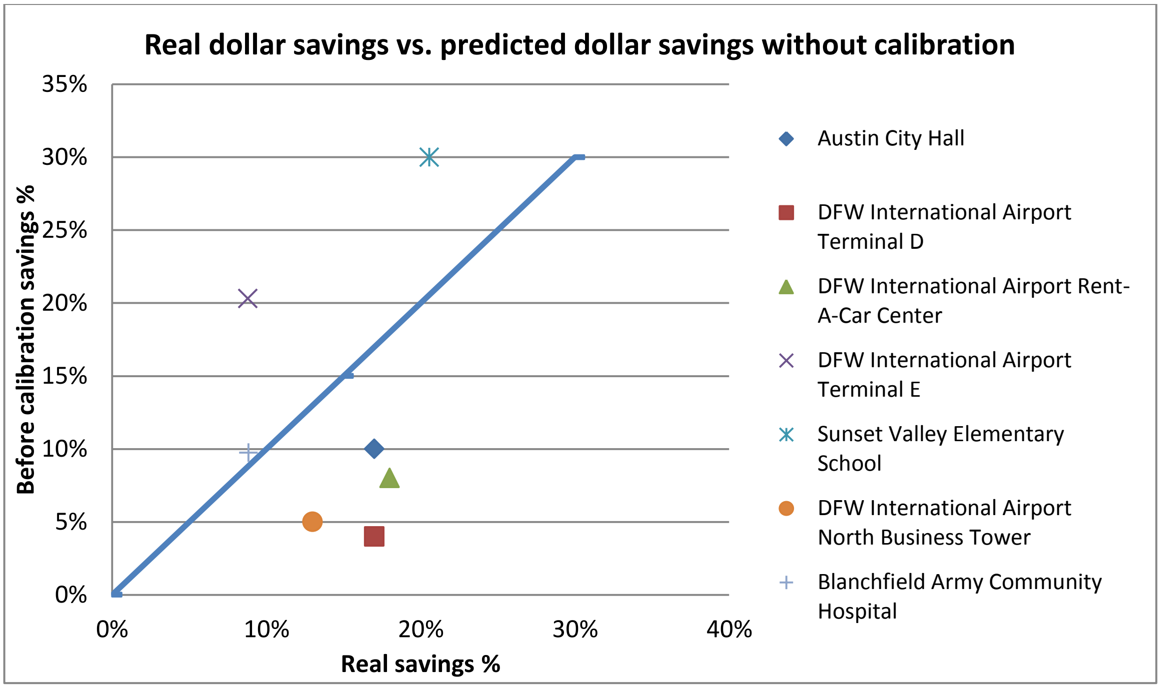



**Figure 6-7** Real dollar savings vs. predicted dollar savings without calibration

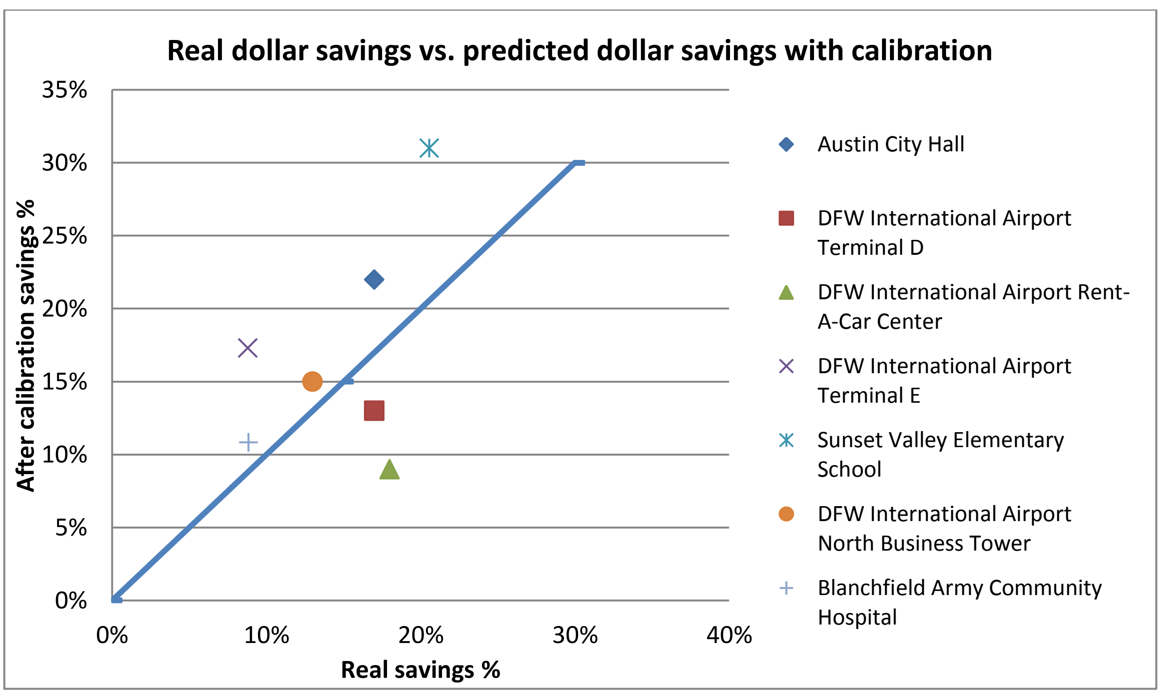



**Figure 6-8** Real dollar savings vs. predicted dollar savings with calibration

Figure 6-8 shows that almost all of the results from the models with calibration are closer to the real savings compared with the results in Figure 6-7, except for the two projects mentioned earlier. In general, calibrating the model allows the user to generate estimated savings that are closer to the measured savings.

# 7. CONCLUSIONS

This research has involved the two main tasks for evaluating the performance of WinAM 4.3. Task 1 is sensitive analysis for the 14 parameters in WinAM 4.3, the other task is the predicted savings analysis. The 162 artificial energy models have been used for sensitivity analysis and seven real projects have been studied for predicted energy savings analysis.

The 162 energy models were generated based on adjusting 14 parameters which were selected from WinAM4.3. The parameters are: 1) outside air percentage, 2) interior zone percentage, 3) window and wall ratio, 4) minimum airflow ratio, 5) maximum airflow ratio, 6) zone temperature setpoint, 7) cooling coil temperature setpoint, 8) lighting load, 9) fan power, 10) night plug load, 11) wall R-value, 12) window U-value, 13) roof U-value, and 14) occupancy.

The seven real projects are:

- Austin City Hall (ACH) (Zhou et al. 2009)
- Blanchfield Army Community Hospital (BACH) (Bes-Tech Inc. and ESL 2009b)
- North Business Tower of DFW International Airport (ESL 2010b)
- Rent-A-Car Center of DFW International Airport (Zeig et al. 2004)
- Sunset Valley Elementary School (SVES) (Yagua et al. 2009)
- Terminal D of DFW International Airport (ESL 2010a)
- Terminal E of DFW International Airport (ESL 2010c)

### 7.1 Conclusion for sensitivity analysis

From Table 6-1 and Table 6-3, the highly sensitive parameters for electric (fan power and lighting plug load) are the same for the system with the economizer and the system without the economizer. Although some of the parameters have different signs, the absolute value is the same (for example, the minimum airflow rate and maximum airflow rate parameters). Highly sensitive parameters include zone temperature setpoint, lighting load, cooling coil temperature, night lighting and plug load, and fan power.

The highly sensitive parameters are also the same with or without the economizer for hot water consumption. In this case, the cooling coil temperature setpoint and zone temperature setpoint are also among the most highly sensitive parameters. In addition to these two parameters, which rank at the top in sensitivity, other highly sensitive parameters include the minimum airflow rate, window U-value, and window-wall ratio.

The parameter sensitivity ranks are similar with or without the economizer for chilled water consumption. The zone temperature setpoint is the most sensitive parameter for the system with the economizer. The system without the economizer ranks zone temperature setpoint as the second most sensitive parameter, following the cooling coil temperature setpoint. In the system with the economizer, the cooling coil temperature setpoint is the most sensitive parameter. In both systems, the minimum airflow rate is the third most sensitive parameter.

From Table 6-2, the least sensitive parameters for electric consumption (0% error percentage) are window-wall ratio, window U-value, peak occupancy, wall U-value, roof U-value, and outside air percentage for electric consumption. This is true for both the system with the economizer and the system without the economizer. Night light and plug load parameter and roof U-value are the least sensitive parameters for chilled water consumption. Maximum airflow rate, fan power and outside air percentage are the least sensitive parameters for hot water consumption. It is not necessary to detect the exact value of the least sensitive parameters; the estimated value can be used according to the WinAM 4.3 help manual: how to use WinAM to calculate savings from energy conservation measures (ESL 2013a). The engineer may thus devote more time to the more sensitive parameters.

### 7.2 Conclusion for predicted energy savings analysis

ASHRAE Guideline 14 ( ASHRAE 2002) defines a well-calibrated model as having NMBE within $\pm$ 5% and the CV(RMSE) is within $\pm$ 15% when calibrated with monthly measured data. The lower the NMBE and CV(RMSE) are, the closer the calibrated model is to the real project. When comparing the NMBEs and CV(RMSE)s for the models without calibration in Table 7-1 with the deviations in Table 7-2, in each case, after calibration the values are reduced. This demonstrates how calibrating the model with WinAM 4.3 can improve the model’s quality.

**Table 7-1** NMBEs and CV(RMSE)s for models without calibration

| | Project number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
| Before Calibration | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) |
| Electric | 20% | 20% | 32% | 32% | 107% | 100% | 13% | 19% | -6% | 12% | 76% | 76% | -48% | 49% |
| Chilled water | 57% | 56% | 41% | 41% | | | -6% | 13% | | | 32% | 32% | | |
| Hot water | 43% | 40% | 87% | 87% | | | 12% | 41% | -38% | 59% | 30% | 46% | 77% | 77% |

**Table 7-2** NMBEs and CV(RMSE)s for models with calibration

| | Project number | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | |
| After Calibration | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) | NMBE | CV (RMSE) |
| Electric | 1% | 8% | -13% | 26% | 5% | 6% | -3% | 13% | -7% | 13% | -1% | 9% | -27% | 31% |
| Chilled water | 30% | 33% | -21% | 57% | | | -1% | 7% | | | 16% | 20% | | |
| Hot water | -23% | 27% | -23% | 24% | | | -1% | 36% | -46% | 61% | -14% | 31% | 17% | 22% |

From the comparison between the predicted savings and the real savings in Table 6-5, five of six calibrated model's deviations have been reduced, which implies the results from the predicted energy savings have been improved by calibrating the models with WinAM 4.3. The model for Sunset valley elementary school cannot be calibrated, as described in Section 6.

### 7.3 Future work

For sensitivity analysis, suggestions for future work are:

1. Consider adjusting the parameters for more HVAC systems, for example, DDVAV system, DDCAV system, and SDCAV system.
2. Consider using different weather data for the same project, this research only uses the weather data from Austin, Texas. Applying different climate zone's data to the model is useful for generating highly sensitive parameters for each climate zone.
3. Consider adjusting the 14 parameters to the real project; in this way this methodology can give the direct instruction for the real CC® project.

For predicted energy savings analysis, suggestions for future work are:

1. Apply the same method to the newest version of WinAM 4.4, compare with the results obtained from WinAM 4.3. If the results have been improved compared with WinAM 4.3, this means that the new functions that have been applied to WinAM 4.4 work well.

2. Calculate the savings caused by the CC® measures that cannot be applied to the WinAM 4.3 models. Include this energy savings in the predicted energy savings; in this way, the savings can be directly compared with the real savings.

## REFERENCES


ASHRAE. 2002. ASHRAE Guideline 14-2002, Measurement of Energy and Demand Savings. Atlanta, GA. Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Bes-Tech Inc., and ESL. 2009a. Continuous Commissioning® final report for Blanchfield Army Community Hospital, Fort Campbell, KY.

Bes-Tech Inc, and ESL. 2009b. Continuous Commissioning® Final Report for Bayne-Jones Army Community Hospital, Fort Polk, LA.

Crawley, D. B. 2004. EnergyPlus: New, capable, and linked. Architectural and Planning Research 21(4): 292-302.

Effinger, M., D. Song, and B. Juan-Carlos. 2008. Continuous Commissioning® Report for Fox Martin Army Community Hospital, Fort Benning, GA.

ESL. 2010a. Continuous Commissioning® of Terminal D, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

ESL. 2010b. Continuous Commissioning® of North Business Tower DFW International Airport final report, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

ESL. 2010c. HVAC system imbalance at Terminal E and Continuous Commissioning® of Terminal E, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

ESL. 2012. WinAM User's Manual, Version 4.3, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

ESL. 2013a. How to use WinAM to calculate savings from energy conservation measures, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

ESL. 2013b. CC® Compass—online tools for Continuous Commissioning®. Retrieved from http://cc-compass-beta.tamu.edu/

Google Maps. 2013. Blanchfield Army Community Hospital, Fort Campbell, Kentucky. Retrieved from https://maps.google.com/maps?q=Blanchfield+Army+Community+Hospital&hl=en&ll=36.636472,-87.447417&spn=0.001726,0.00305&sll=30.590851,-96.291661&sspn=0.14777,0.338173&hq=Blanchfield+Army+Community+Hospital&t=h&z=19&iwloc=A

Helton, J. C. 2006. Survey of sampling-based methods for uncertainty and sensitivity analysis. Reliability Engineering and System Safety 91(10): 1175-1209.

Henninger, R. H., and M. J. Witte. 2001. EnergyPlus Testing with ANSI/ASHRAE Standard 140-2001 (BESTEST). Park Ridge, IL: Gard Analytics.

HHS Associates LLC, and ESL. 2009a. Continuous Commissioning® for Tripler Army Medical Center, Honolulu, HI.

HHS Associates LLC, and ESL. 2009b. Continuous Commissioning® Follow-Up Report for Fox Army Health Center, Redstone Army Arsenal, Huntsville, AL.

Hirsch, J. and Associates. 2010. eQUEST introductory tutorial (version 3.64). Camarillo, CA.

Hopfe, C. J., J. L. M. Hensen, and W. Plokker. 2007. Uncertainty and sensitivity analysis for detailed design support. Proceedings of 10th IBPSA Building Simulation Conference, Beijing: Tsinghua University, 1799-1804.

Hopfe, C. J., and J. L. M. Hensen. 2011. Uncertainty analysis in building performance simulation for design support. Energy and Buildings 43(10): 2798-2805

Lam, J. C. 2008. Sensitivity analysis and energy conservation measures implications. Energy Conversion and Management 49(11): 3170-3177.

Litko, J. R. 2005. Sensitivity analysis for robust parameter design experiments. Proceedings of the 37th Conference on Winter Simulation, Winter Simulation Conference, Orlando, FL, 2020-2025.

Liu, M., D. E. Claridge, W. D. Turner. 2002. Continuous Commissioning® guidebook: Maximizing building energy efficiency and comfort. Federal Energy Management Program (FEMP), U.S. Department of Energy.

Lomas, K. J., and H. Eppel. 1992. Sensitivity analysis techniques for building thermal simulation programs. Energy and Buildings 19(1): 21-44.

Petr, K., J. Filip, K. Kabele, and J. Hensen. 2007. Technique of uncertainty and sensitivity analysis for sustainable building energy systems performance calculations. Proceedings of 10th IBPSA Building Simulation Conference, Tsinghua University, Beijing, 629-636.

Purdy, J., and I. Beausoleil-Morrison. 2001. The significant factors in modelling residential buildings. Proceedings of Building Simulation, Seventh International Building Performance Simulation Association Conference, Rio de Janeiro, Brazil, 207-214.

Spitler, J. D., D. E. Fisher, and D. C. Zietlow. 1989. A primer on the use of influence coefficients in building simulation. Proceedings of Building Simulation' 89 conference. 299-304.

Struck, C. 2009. An investigation of the option space in conceptual building design for advanced building simulation. Advanced Engineering Informatics 23(4): 386-395.

Struck, C., and J. Hensen. 2006. Uncertainty analysis for conceptual building design – A review of input data. Proceedings of the 1st Int. IBPSA Germany/Austria Conf. BauSIM, October, Munich, Germany, 199-202.

Tian, W. 2013. A review of sensitivity analysis methods in building energy analysis. Renewable and Sustainable Energy Reviews 20(0): 411-419.

Yagua, C., G. Napper, G. Wei, J. Baltazar-Cervantes, D. Turner, and D. Claridge. 2009. Continuous Commissioning® report for Delco Activity Center, Sunset Valley Elementary School, and Burnet Middle School, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station,TX.

Zeig, G., H. Huff, T. Giebler, K. Milligan, J. Baltazar-Cevantes, G. Wei, B. Yazdani, and D. Turner. 2004. Technical assistance report for DFW International Airport Rent-A-Car Center and Terminal B, Energy Systems Laboratory, Texas Engineering

Experiment Station, College Station, TX.

Zhou, J., C. Yagua, G. Wei, J. Baltazar-Cevantes, S. Deng, D. Turner, M. Verdict, and D. Claridge. 2009. Continuous Commissioning® report and BAS sequence of operation for Austin City Hall, Energy Systems Laboratory, Texas Engineering Experiment Station, College Station, TX.

# APPENDIX A

For making the comparison between eQUEST and WinAM as close as possible, the weather data used in WinAM should be used in eQUEST.

The steps for generating the weather data for eQUEST are as follows:

## A.1 Convert the ".bin" weather file into a ".ft" weather file

The user needs to download "DOE22WeatherUtilities.zip" from the website www.doe2.com.

After downloading, unzip this file to any local root hard drive. Create a new folder and name it "WEATHER" in "C:\DOE22".

Copy the weather file in TMY2 to the WEATHER file in DOE22. The user than needs to run the DOS command box.

The method to run the DOS command box is:

- From Start button, select "Run".
- In the jumped out window input "cmd" and click "OK" in the DOS command box.
- Get in to C:\ first by inputting "cd C:\" and launch into "C:\DOE22\UTIL32" by typing "cd \DOE22\UTIL32".

To convert the weather file successfully, the user needs the tool named “MKAFT.bat” (‘make a .ft file’, “ft” is the extension which means the file is the “unzipped” DOE2-2/eQUEST weather file).

If the user named the “.bin” weather file for example “Austin.bin”, then the user needs to input “mkaft Austin” in the DOS command window, e.g. “**C:\DOE22\UTIL32**>mkaft Austin.” In this way, users will get the unzipped weather file to check.

- The reason to do this step first is that the experiment in this research needs to keep the dry bulb temperature, wet bulb temperature and dew point temperature exactly the same both in eQUEST and WinAM.

**A.2 Convert the “.ft” weather file into an “.epw” weather file**

EnergyPlus is the required download software for converting weather files. The software offered by EnergyPlus entitiled *Weather Statistics and Conversions* will be used. The initial interface is shown in Figure A-1

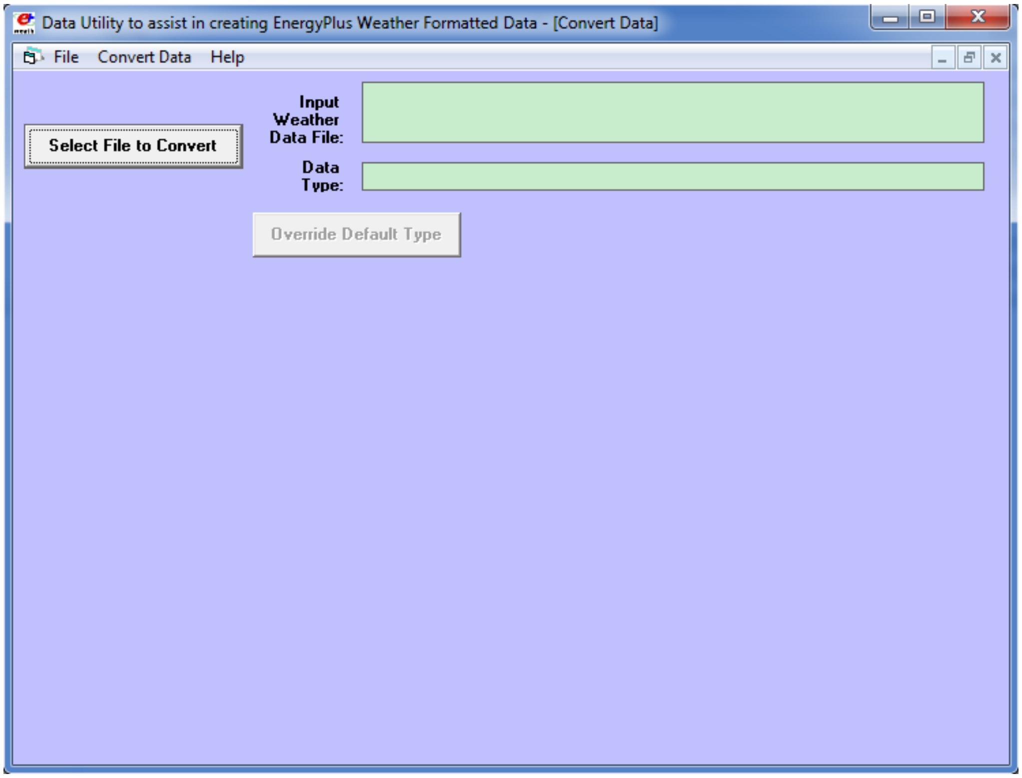


**Figure A-1** Initial interface of weather statistics and conversions

The steps for using this software are:

- Click "Select File to Convert" button
- Choose select output format as *"EnergyPlus weather format (EPW)"* and decide where will be the proper place to save the new weather file, see Figure A-2. After that, the conversion can be done.

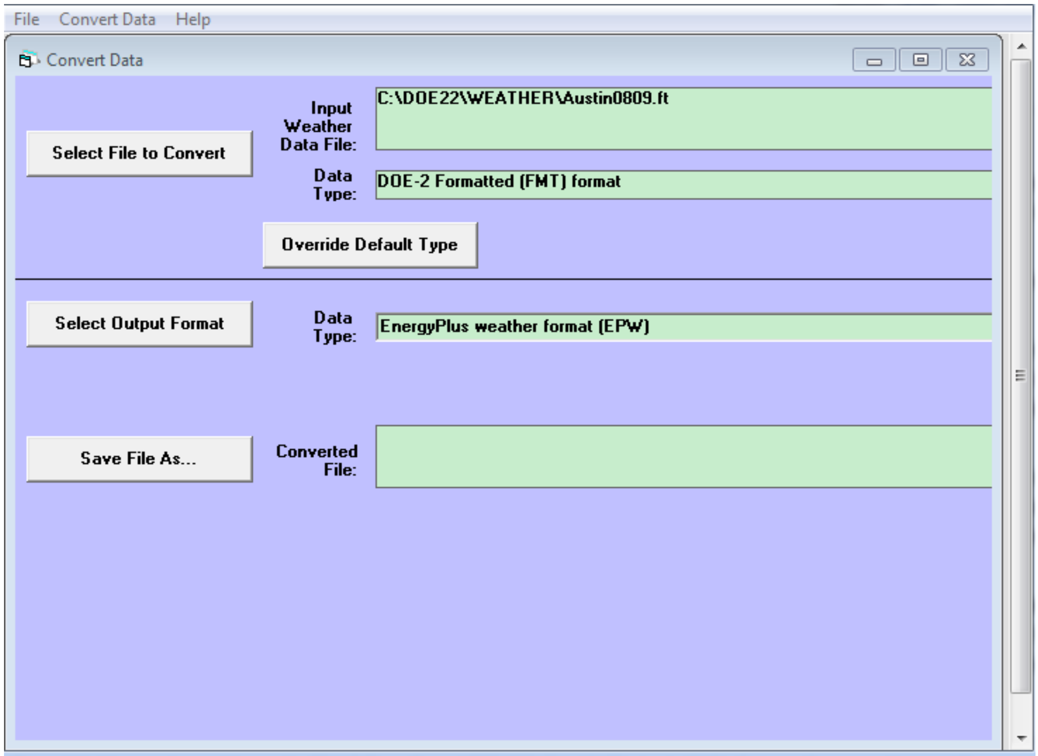



**Figure A-2** After applying the conversion command

### A.3 Convert ".epw" weather file into a ".cvs" weather file

Repeat the process in step A.2 Convert the ".ft" weather file into an ".epw" weather file. Then convert the ".epw" file into a ". cvs" file.

After setting up the ".cvs" weather file, retrieve the weather data used for WinAM. Obtain the weather data from the CC-compass website, and convert the units used in the WinAM weather file from Fahrenheit to Celsius before copying the dry bulb temperature and dew point temperature to the converted ".cvs" file. Delete the other nonrelative information in the converted ".cvs" weather file. The purpose is to have exactly the same weather file that can be used for both WinAM and eQUEST.

- There is no other weather information in the weather file used for WinAM, e.g. wind speed, solar direction etc. The “.bin” file used for eQUEST has this information.

### A.4 Convert edited “ .cvs” file back into an “.epw” file

This method is similar to step A.2 Convert the “.ft” weather file into an “.epw” weather file. The difference compare with step A.2 is pick up the output format with the one has “.epw” option.

### A.5 Convert edited “.epw” weather file into a “.bin” weather file.

Software DOE-2 processor is required here. After this process, the edited weather file is ready to be used.

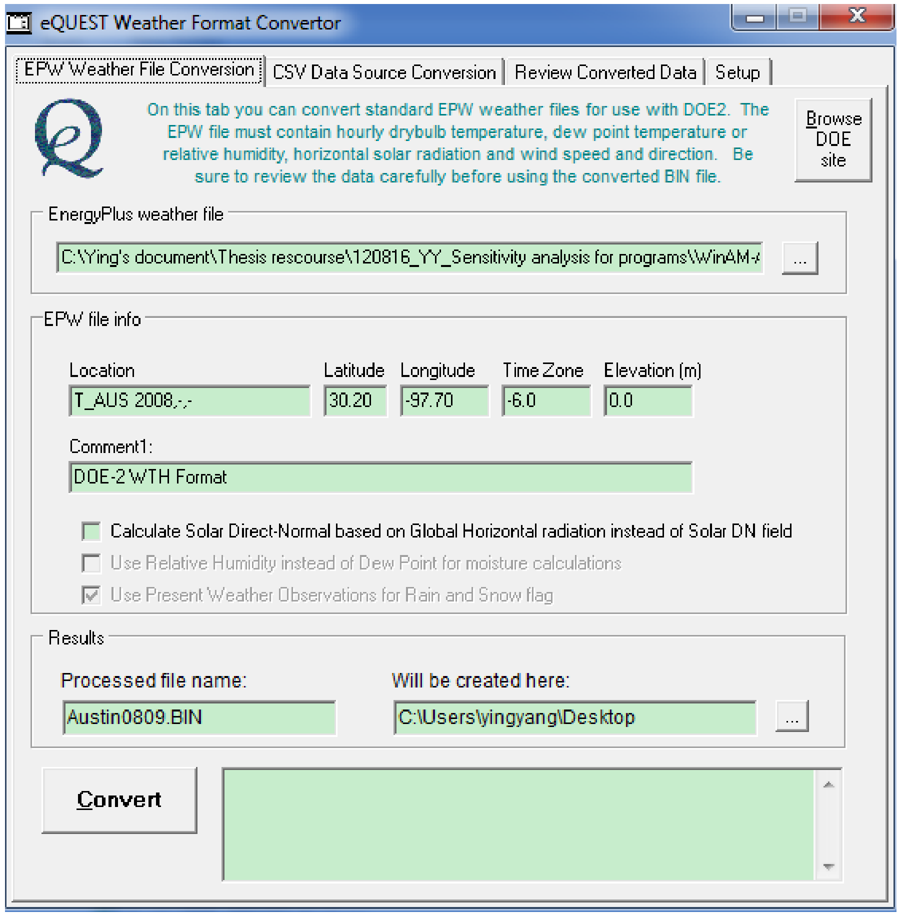



**Figure A-3** DOE-2 Processor

## APPENDIX B

In this section, the results for the calibration task and the CC® measures applied to the WinAM 4.3 model and the real project will be discussed.

### B.1 Austin City Hall

For comparing WinAM 4.3 with the popular building performance software eQUEST 3.64, the model for Austin City Hall has been simulated by both programs.

Table B-1 shows the results for annual energy consumption from both programs and the bias error between them. The results show these two programs are not suitable for comparison with each other directly. Under this situation, the comparison between the savings percentages for each program has been done in Table B-3.

**Table B-1** Annual energy consumption for baseline models, without calibrating the model.

| | WinAM 4.3 | eQUEST 3.64 | $\frac{(\text{WinAM} - \text{eQUEST})}{\text{eQUEST}}$ |
|---|---|---|---|
| Chilled Water(MMBtu) | 6,408 | 11,780 | -46% |
| Natural Gas(MMBtu) | 1,759 | 2,239 | -21% |
| Electric(kWh) | 2,562,473 | 1,794,400 | 43% |

**Table B-2** CC® Measures for Austin City Hall

| CC® Measures applied to Austin City Hall **WinAM 4.3 model** | CC® Measures applied to Austin City Hall **project** |
|---|---|
| 1. Outside airflow percentage | 1. Outside airflow percentage |
| 2. Minimum airflow rate | 2. Minimum airflow rate |
| 3. Economizer | 3. Economizer |
| 4. Preheat | 4. Preheat |
| | 5. Demand-controlled ventilation using CO2 sensors for garage |
| | 6. AHU duct static pressure reset |
| | 7. Hot water loop DR reset |
| | 8. Discharge air temperature reset based on both minimum and maximum box load |
| | 9. Hot water supply temperature reset |

Table B-3 gives the results of the savings before CC® measures and after CC® measures compared with the baseline model.

The equation for calculating the savings percentage is:

$$\frac{Energy\ consumption\ before\ CC^{®}\ \text{measures} - Energy\ consumption\ after\ CC^{®}\ \text{measures}}{Energy\ consumption\ before\ CC} * 100\% = Savings\ \% \qquad \text{Equation B-1}$$

**Table B-3** Savings percentage before CC® measures and after CC® measures

| Item | WinAM | eQUEST |
|---|---|---|
| Chilled Water(MMBtu) | 25% | 32% |
| Natural Gas(MMBtu) | 22% | 84% |
| Electric(kWh) | 2% | 1% |

Although in Table B-3, the same CC® measures have been applied to this program.  The gas consumption is the huge difference there. Part of the reason may be differences that exist between WinAM 4.3 and eQUEST 3.64 that have been documented in Section 5.

Table B-4 and Table B-5 are the energy savings results calculated before CC® measures and after CC® measures for the model without calibration and the model with calibration. According to the results, after calibration the savings have been overestimated. This is due to the natural gas savings being 49% higher than the savings from the CC® report which increases the total savings percentage.

**Table B-4** Energy savings for the model without calibration in dollars for Austin City Hall

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Total Electric | kWh | 2% | 12% | 10% | 17% |
| Natural Gas | MMBtu | 27% | 18% | | |
| District Chilled Water | MMBtu | 24% | 45% | | |

**Table B-5** Energy savings for the model with calibration in dollars for Austin City Hall

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Total Electric | kWh | 3% | 12% | 22% | 17% |
| Natural Gas | MMBtu | 67% | 18% | | |
| District Chilled Water | MMBtu | 43% | 45% | | |

## B.2 Dallas/Fort Worth (DFW) International Airport Terminal D

Table B-6 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for DFW international airport Terminal D.

**Table B-6** CC® measures for DFW Terminal D

| CC® Measures applied to DFW international airport Terminal D **WinAM 4.3 model** | CC® Measures applied to DFW international airport Terminal D **project** |
|---|---|
| 1. Minimum airflow rate | 1. Minimum airflow rate |
| 2. Cooling coil temperature reset | 2. Cooling coil temperature reset |
| | Improvement measures are different for each single AHU, and in this project there are more than 15 different improvements that have been applied to more than 50 AHUs |

Table B-7 and Table B-8 are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-7** Energy savings for the model without calibration in dollars

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 2% | 10% | 4% | 17% |
| Chilled water | MMBtu | 6% | 26% | | |
| Hot water | MMBtu | 52% | 49% | | |

**Table B-8** Energy savings for the model with calibration in dollars

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 11% | 10% | 13% | 17% |
| Chilled water | MMBtu | 16% | 26% | | |
| Hot water | MMBtu | 22% | 49% | | |

## B.3 DFW International Airport Rent-A-Car Center

Table B-9 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for DFW international airport Rent-A-Car Center.

Table B-10 and Table B-11are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-9** CC® measures for DFW Rent-A-Car Center

| CC® Measures applied to DFW international airport Rent-A-Car Center **WinAM 4.3 model** | CC® Measures applied to DFW international airport Rent-A-Car Center **Project** |
|---|---|
| 1. Outside airflow percentage | 1. Outside airflow percentage |
| 2. Cooling coil temperature reset | 2. Cooling coil temperature reset |
| 3. Reduce non-HVAC electric usage | 3. Reduce non-HVAC electric usage |
| 4. Minimum airflow | 4. Minimum airflow |
| | 5. AHU duct static pressure reset |
| | 6. Chiller operation reset |
| | 7. Chiller temperature reset |
| | 8. Condenser water temperature reset |
| | 9. Secondary pump control reset |

**Table B-10** Energy savings for the model without calibration in dollars

| Without Calibration | | |
|---|---|---|
| Item | Saving | Savings From CC® Report |
| Electric | 8% | 18% |

**Table B-11** Energy savings for the model with calibration in dollar

| With Calibration | | |
|---|---|---|
| Item | Saving | Savings From CC® Report |
| Electric | 9% | 18% |

**B. 4 DFW international airport Terminal E**

Table B-12 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for DFW international airport Terminal E.

Table B-13 and Table B-14 are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-12** CC® measures for DFW Terminal E

| CC® Measures applied to DFW international airport Terminal E **WinAM 4.3 model** | CC® Measures applied to DFW international airport Terminal E **project** |
|---|---|
| 1. AHU operation schedule | 1. AHU operation schedule (zone temperature) |
| 2. Occupied/Unoccupied mode | 2. Occupied/Unoccupied mode |
| 3. Cooling coil temperature reset | 3. Cooling coil temperature reset |
| 4. Zone temperature | 4. Zone temperature (occupied and unoccupied mode) |
| | 5. AHU duct static pressure reset |
| | 6. Minimum airflow rate reset based on cooling and heating mode |

**Table B-13** Energy savings for the model without calibration in dollars

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 19% | 7% | 20% | 9% |
| Chilled Water | MMBtu | 43% | 5% | | |
| Hot Water | MMBtu | -17% | 25% | | |

**Table B-14** Energy savings for the model with calibration in dollars

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 10% | 7% | 17% | 9% |
| Chilled Water | MMBtu | 33% | 5% | | |
| Hot Water | MMBtu | 35% | 25% | | |

**B. 5 Sunset Valley Elementary School**

Table B-15 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for Sunset Valley Elementary School

Table B-16 and Table B-17 are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-15** CC® measures for Sunset Valley Elementary School

| CC® Measures applied to Sunset Valley Elementary School **WinAM 4.3 model** | CC® Measures applied to Sunset Valley Elementary School **project** |
|---|---|
| 1. Hot deck (DDCAV) reset | 1. Hot deck (DDCAV) reset |
| 2. Cold deck (DDCAV) reset | 2. Cold deck (DDCAV) reset |
| 3. Economizer | 3. Economizer |
| 4. Chiller operation strategy | 4. Chiller operation strategy |
| | 5. Boiler operation strategy |

**Table B-16** Energy savings for the model without calibration in dollars

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 24% | 19% | 30% | 26% |
| Natural Gas | MMBtu | 57% | 45% | | |

**Table B-17** Energy savings for the model with calibration in dollars

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 25% | 19% | 31% | 21% |
| Natural Gas | MMBtu | 61% | 45% | | |

### B.6 DFW International Airport North Business Tower

Table B-18 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for DFW international airport North Business Tower

Table B-19 and Table B-20 are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-18** CC® measures for DFW North Business Tower

| CC® Measures applied to DFW international airport North Business Tower **WinAM 4.3 model** | CC® Measures applied to DFW international airport North Business Tower **project** |
|---|---|
| 1. Cooling coil temperature reset | 1. Cooling coil temperature reset |
| 2. Return fan | 2. Return fan |
| 3. Preheat temperature reset | 3. Preheat temperature reset |
| 4. Zone temperature | 4. Zone temperature (occupied and unoccupied mode) |
| | 5. AHU duct static pressure reset based on OAT |
| | 6. Occupied schedule for static pressure reset and supply air temperature |
| | 7. Hot water supply temperature reset |
| | 8. Hot water pump enable reset |

**Table B-19** Energy savings for the model without calibration in dollars

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 6% | 4% | 5% | 13% |
| Chilled Water | MMBtu | 15% | 13% | | |
| Hot Water | MMBtu | -6% | 53% | | |

**Table B-20** Energy savings for the model with calibration in dollars

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 8% | 4% | 15% | 13% |
| Chilled Water | MMBtu | 22% | 13% | | |
| Hot Water | MMBtu | 24% | 53% | | |

**B.7 Blanchfield Army Community Hospital**

Table B-21 is the CC measures have been applied to the WinAM 4.3 model and the real CC® measures for Blanchfield Army Community Hospital.

Table B-22 and Table B-23 are the energy savings for applying the CC® measures to the project without calibration and with calibration.

**Table B-21** CC® measures for Blanchfield Army Community Hospital

| CC® Measures applied to BACH **WinAM 4.3 model** | CC® Measures applied to BACH **project** |
|---|---|
| 1. Cold deck | 1. Cold deck |
| 2. Economizer | 2. Economizer ( with enable schedule) |
| | 3. Zone temperature reset based on occupied and unoccupied mode |
| | 4. Relative humidity ratio reset |
| | 5. Reset cold deck and hot deck temperature based on both OAT and occupied and unoccupied mode |
| | 6. Reset mixed air temperature |
| | 7. AHU duct static pressure |

**Table B-21** continued

| CC® Measures applied to BACH **WinAM 4.3 model** | CC® Measures applied to BACH **project** |
|---|---|
| | 8. Supply temperature reset based on OAT and zone temperature |
| | 9. Condensed water temperature reset |
| | 10. Reduce steam pressure of Boiler |

**Table B-22** Energy savings for the model without calibration in dollars

| Without Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Saving | Total Saving From CC® Report |
| Electric | kWh | 8% | 14% | 10% | 9% |
| Natural Gas | MMBtu | 17% | 2% | | |

**Table B-23** Energy savings for the model with calibration in dollars

| With Calibration | | | | | |
|---|---|---|---|---|---|
| Item | Units | Savings | Savings From CC® Report | Total Savings | Total Savings From CC® Report |
| Electric | kWh | 11% | 14% | 11% | 9% |
| Natural Gas | MMBtu | 11% | 2% | | |

## APPENDIX C

**Table C-1** WinAM friendly Continuous Commissioning® report suggestions

| Checklist | Content | Note |
|---|---|---|
| 1st | **Cover page** | Must have |
| 2nd | **Disclaimer** | Must have |
| 3rd | **Acknowledgements** | Must have |
| 4th | **Executive Summary** | Must have |
| 5th | **Table of Contents** | Must have |
| 6th | **Introduction:**<br>1) Project location.<br>2) Time period when CC® measures are applied to the building system.<br>3) Gross area and the window-wall ratio of the project buildings.<br>4) Different AHU systems in the project building and the serving area for each type.<br>5) Cooling system and heating system efficiency.<br>6) The total HP and control strategy for pumps.<br>7) Non-HVAC and Outside Lighting Usage. | 1) This information is helpful in obtaining weather data.<br>2) It is suggested that the time periods when CC® measures are started and ended are recorded. This will help the WinAM modeler specify the accurate length of time that CC® measures have been applied to the project.<br>3) The WinAM modeler can use this data directly.<br>4) The energy consumption of different AHU systems is different.<br>5) The WinAM modeler can use this data directly.<br>6) The WinAM modeler can use this data directly.<br>7) This part of electric consumption can cause an error of when calibrating the electric usage. |

**Table C-1** continued

| Checklist | Content | Note |
|---|---|---|
| 7th | **HVAC System Operation prior to the CC® process:**<br>1) Does the AHU have preheat, precool or return fan?<br>2) AHU operation schedule.<br>3) Minimum and maximum airflow ratio.<br>4) Minimum outside air percentage or airflow ratio.<br>5) Economizer<br>6) Cooling/Hot water coil temperature setpoint.<br>7) Zone temperature setpoint.<br>8) Occupancy schedule<br>9) Equipment operation schedule for both occupied hours and unoccupied hours.<br>10) Fan type.<br>11) Static pressure setpoint. | These eleven items will assist the WinAM modeler simulate a model that is close to the real project. It is more flexible for items 4, 8 and 9 in this checklist. And Items 10 and 11 are the new functions in WinAM 4.4 which are documented in this checklist. |
| 8th | **Observed problems and maintenance issues** | This part is useful for adjusting the base case WinAM model to make it as close as possible to the real project building. |
| 9th | **CC® measures** | In this section the report writer should specify every step they have performed, in as much detail as possible.<br>The engineer can go back to the 6th and 7th in this checklist for reference. |
| 10th | **Operation and Maintenance** | |

**Table C-1** continued

| Checklist | Content | Note |
|---|---|---|
| 11th | **Savings after applying CC® measures to the projects** | |
| 12th | Appendix A | |
| 13th | Appendix B | |

This list is designed as the base guideline to document WinAM friendly Continuous Commissioning® reports. The engineers can add more information to prepare the report.